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This article is a commentary on Brossier et al. (2022), https://doi.org/10.1029/2022GL099765.

Key Points:

- The manuscript by Brossier et al. (2022, https://doi.org/10.1029/2022GL099765) extends the successful approach and methodology used by previous work
- We comment here on the main results by Brossier et al. (2022, https://doi.org/10.1029/2022GL099765) and discuss the important implications for the future investigations of Venus
- Their results add further lines of evidence indicating possibly recent volcanism on Venus

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Geologically Recent Areas as One Key Target for Identifying Active Volcanism on Venus

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Abstract The recently selected NASA VERITAS and DAVINCI missions, the ESA EnVision, the Roscosmos Venera-D will open a new era in the exploration of Venus. One of the key targets of the future orbiting and in situ investigations of Venus is the identification of volcanically active areas on the planet. The study of the areas characterized by recent or ongoing volcano-tectonic activity can inform us on how volcanism and tectonism are currently evolving on Venus. Following this key target, Brossier et al. (2022, https://doi.org/10.1029/2022GL099765) extend the successful approach and methodology used by previous works to Ganis Chasma in Atla Regio. Here we comment on the main results published in Brossier et al. (2022, https://doi.org/10.1029/2022GL099765) and discuss the important implications of their work for the future orbiting and in situ investigation of Venus. Their results add further lines of evidence indicating possibly recent volcanism on Venus.

1. The Importance of Identifying Volcanically Active Areas in the Future Exploration of Venus

The exploration of Venus will go through a new golden era thanks to the recently selected NASA Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (VERITAS) (Smrekar et al., 2020) and Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging (DAVINCI) (Garvin et al., 2022) missions, the ESA EnVision mission (Ghail et al., 2020), and the Roscosmos Venera-D mission (Zasova et al., 2019). Moreover, other two missions are currently being evaluated for selection: the ISRO Shukrayaan-1 mission (i.e., Haider et al., 2018; Sundararajan, 2021) and the Chinese VOICE mission (e.g., Wang et al., 2022). These missions will focus on the analysis of the chemical composition of the atmosphere and the geologic features of Venus.

One of the main targets of the future missions to Venus will be the identification of potentially volcanically active areas on Venus (i.e., Filiberto et al., 2020; Smrekar et al., 2010). Identifying the locations of possibly active volcanism with its related composition is crucial to estimate energy and volatile budget on Venus, that is of great importance to understand the geodynamic evolution of Venus and the terrestrial planets. Evidence of ongoing volcanism can give us clues in the debate between catastrophic (i.e., Basilevsky & Head, 1995; Romeo & Turcotte, 2010; Schaber et al., 1992) and equilibrium resurfacing (i.e., Guest & Stofan, 1999; O'Rourke et al., 2014; Phillips et al., 1992), indicating how volcanic and tectonic activity is currently evolving on Venus (e.g., Weller & Kiefer, 2020). The analysis of recently erupted (chemically unweathered) lava flows will also provide useful information about the volatile content of the mantle of Venus (e.g., Filiberto, 2014). We comment here the results of the work by Brossier et al. (2022) and the related implications for the future orbiting and in situ investigations of Venus.

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As observed by previous studies (e.g., Pettengill et al., 1992), the presence of high dielectric (ferroelectric) minerals can increase the radar reflectivity and lower the radar emissivity on Venus. It is observed that some minerals (e.g., perovskite oxides and chlorapatite) can lower the emissivity even at anomalously low altitudes (Brossier et al., 2021). Theoretical studies indicate that the high dielectric minerals can be formed over the time by the interactions between the surface and lower atmosphere, also known as chemical weathering (e.g., Zolotov, 2019). In this way, dielectric measurements on Venus can be used as a potential chronometer to constrain the age of surface materials.

Brossier et al. (2022) analyze the radar emissivity excursions of seven different sites at Ganis Chasma, four of which already studied by Shalygin et al. (2015) using Venus Monitoring Camera (VMC) data of the Venus Express, while other three sites were selected separately for comparison (Figure 1). Their results show that for a given (range of) altitude and temperature, the emissivity excursions do not occur uniformly over all the analyzed surface materials (Figure 2). This implies that, in the study area, the observed emissivity excursions are mainly controlled by the presence (or absence) of distinct ferroelectric minerals with high dielectric constant. Based on the magnitude of the observed radar emissivity excursions of the seven different sites, the authors conclude that sites 1, 3, and 4 may be characterized by unweathered and thus extremely young surface materials where high dielectric minerals have not yet been formed.

Other recent studies have combined laboratory results, geologic interpretation, and Venus Express VIRTIS 1 micron surface emissivity data to provide additional lines of evidence for recently or possibly ongoing volcano-tectonic activity at Idunn Mons, the major volcanic structure of Imdr Regio on Venus (Cutler et al., 2020; D'Incecco et al., 2017, 2020, 2021a, 2021b, 2021c; Filiberto et al., 2020, 2021; López et al., 2022). Combining this new work with previous studies by Brossier et al. (2020, 2021), this demonstrates that the Magellan data set is able to provide important clues about the materials on the surface, which can be used as a potential chronometer for the surface age of Venus. The results of this manuscript are extremely relevant to our understanding of how volcanic processes are currently acting on Venus. Further, these models can be tested with the upcoming fleet of missions expected to arrive at Venus in the next decade.

The wealth of data to be provided by the future missions will tell us more about ongoing volcanic activity on Venus. For this reason, it is crucial to select a number of relevant volcanically and tectonically active areas on Earth as suitable Venus's analogs. To this regard, Project "Analogs for VENus's GEologically Recent

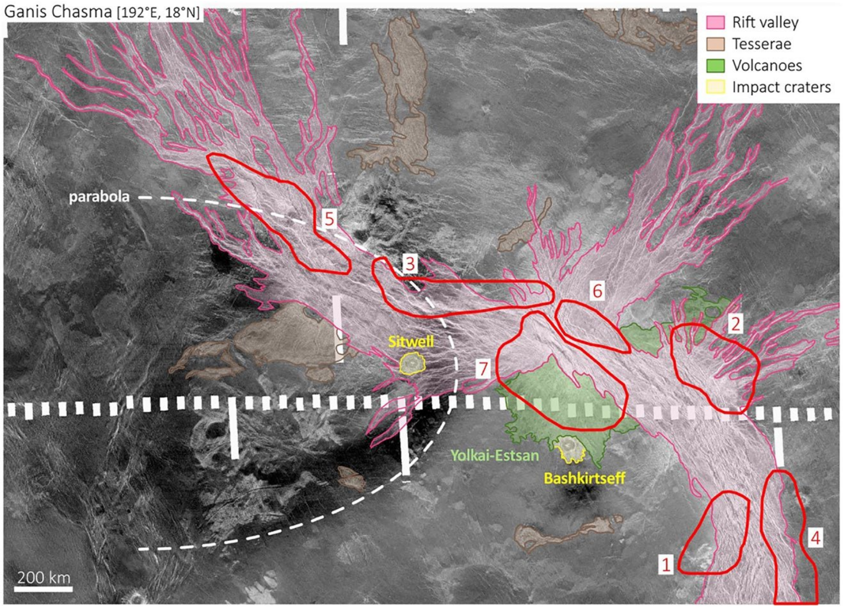

Figure 1. Ganis Chasma (192°E, 18°N) showing Magellan Synthetic Aperture Radar image (gray scale) and the main morphologic features. The seven sites of interest are outlined in red. Morphologic features are mapped after Ivanov and Head (2011): Ganis Chasma (rift zone), Sitwell crater (with its parabola), Bashkirtseff crater, Yolkai-Estsan Mons, and surrounding tesserae. Maps have a simple cylindrical projection and north is up. From Brossier et al. (2022).

10.1029/2022GL101813

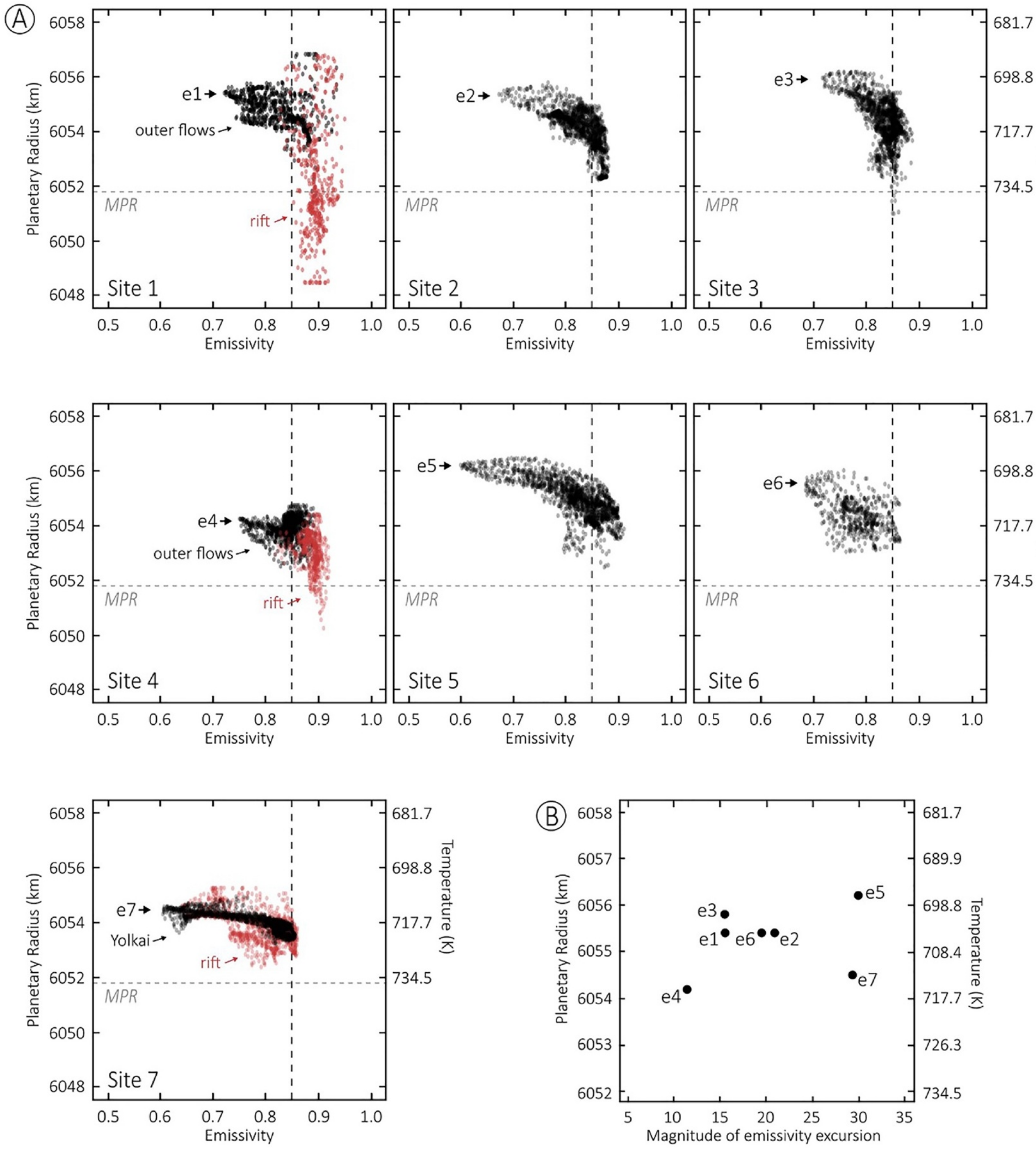

Figure 2. (a) Elevation versus emissivity plots obtained for the studied sites. Dashed lines in plots are mean global values of emissivity at 0.85 (vertical, black), and planetary radius at 6,051.8 km (horizontal, gray). (b) Magnitude of emissivity excursions (percent change from global average value of 0.85) detected in each site versus corresponding altitude and temperature. Temperatures are given by the Vega 2 lander data (Brossier et al., 2020; Lorenz et al., 2018; Seiff, 1987). From Brossier et al. (2022).

Surfaces" (AVENGERS) aims to create a list of suitable analog volcanic sites on Earth, which can help us to: (a) collect spectral signatures from lava flow samples on Earth, whose chemical composition is known, to compare with the spectra to be provided by the future investigations of Venus; (b) analyze radar backscattering over volcanically active areas on Earth to check how to evaluate changes in the areal extent of the lava flows in short amounts of time due to the effect of possibly ongoing eruptions; and (c) use easily accessible volcanic sites on Earth as test areas for drilling operations and in situ elemental analyses. As a first analog site for Project AVENGERS, preliminary studies are currently being conducted on Mount Etna (D'Incecco et al., 2022; Eggers et al., 2022), one of the most active and well monitored volcanoes on Earth. Building off this, studying active and recently active volcanism on the Earth is vital to test models for Venus exploration, such as Brossier et al. (2022) in order to be able to constrain potentially active volcanism and tectonism on Venus with the future missions due to arrive and make repeated measurements over the same surface previously measured by Magellan.

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. (2022), on this journal.

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References

Basilevsky, A. T., & Head, J. W. (1995). Regional and global stratigraphy of Venus: A preliminary assessment and implications for the geologic history of Venus. *Planetary and Space Science*, *43*(12), 1523–1553. https://doi.org/10.1016/0032-0633(95)00070-4

Brossier, J., Gilmore, M. S., & Head, J. W. (2022). Extended rift-associated volcanism in Ganis Chasma, Venus detected from Magellan radar emissivity. *Geophysical Research Letters*, *49*(15), e2022GL099765. https://doi.org/10.1029/2022GL099765

Brossier, J., Gilmore, M. S., Toner, K., & Stein, A. J. (2021). Distinct mineralogy 1 and age of individual lava flows in Atla Regio, Venus derived from Magellan radar emissivity. *Journal of Geophysical Research*, *126*(3). https://doi.org/10.1029/2020JE006722

Brossier, J. F., Gilmore, M. S., & Toner, K. (2020). Low radar emissivity signatures on Venus volcanoes and coronae: New insights on relative composition and age. *Icarus*, *343*, 113693. https://doi.org/10.1016/j.icarus.2020.113693

Cutler, K. S., Filiberto, J., Treiman, A. H., & Trang, D. (2020). Experimental investigation of oxidation of pyroxene and basalt: Implications for spectroscopic analyses of the surface of Venus and the ages of lava flows. *The Planetary Science Journal*, *1*, 21. https://doi.org/10.3847/psj/ab8faf

D'Incecco, P., Filiberto, J., Eggers, G. L., López, I., Mari, N., Monaco, C., et al. (2022). Future orbiting and in-situ exploration of Venus: Mount Etna as a terrestrial analog. In *Paper presented at 17th Congresso Scienze Planetarie, Napoli*.

D'Incecco, P., Filiberto, J., López, I., Gorinov, D. A., & Komatsu, G. (2021a). Idunn Mons: Evidence for ongoing volcano-tectonic activity and atmospheric implications on Venus. *The Planetary Science Journal*, *2*(5), 215. https://doi.org/10.3847/psj/ac2258

D'Incecco, P., Filiberto, J., López, I., Gorinov, D. A., Komatsu, G., Martynov, A., & Pisarenko, P. (2021b). The geologically supervised spectral investigation as a key methodology for identifying volcanically active areas on Venus. *Journal of Geophysical Research: Planets*, *126*(7), e2021JE006909. https://doi.org/10.1029/2021je006909

D'Incecco, P., Filiberto, J., López, I., Gorinov, D., Komatsu, G., Martynov, A., & Pisarenko, P. (2021c). The young volcanic rises on Venus: A key scientific target for future orbital and in-situ measurements on Venus. *Solar System Research*, *55*(4), 315–323. https://doi.org/10.1134/S0038094621040031

D'Incecco, P., López, I., Komatsu, G., Ori, G. G., & Aittola, M. (2020). Local stratigraphic relations at Sandel crater, Venus: Possible evidence for recent volcano-tectonic activity in Imdr Regio. *Earth and Planetary Science Letters*, *546*, 116410. https://doi.org/10.1016/j.epsl.2020.116410

D'Incecco, P., Müller, N., Helbert, J., & D'Amore, M. (2017). Idunn Mons on Venus: Location and extent of recently active lava flows. *Planetary and Space Science*, *136*, 25–33. https://doi.org/10.1016/j.pss.2016.12.002

Eggers, G. L., Filiberto, J., D'Incecco, P., Mari, N., Leone, G., Monaco, C., et al. (2022). Mineralogy and spectroscopy of Mount Etna lava flows as an analogue to Venus. abstract #2255.

Filiberto, J. (2014). Magmatic diversity on Venus: Constraints from terrestrial analog crystallization experiments. *Icarus*, *231*, 131–136. https://doi.org/10.1016/j.icarus.2013.12.003

Filiberto, J., D'Incecco, P., & Treiman, A. H. (2021). Venus, an active planet: Evidence for recent volcanic and tectonic activity. *Elements*, *17*(1), 67–68. https://doi.org/10.2138/gselements.17.1.67

Filiberto, J., Trang, D., Treiman, A. H., & Gilmore, M. S. (2020). Present-day volcanism on Venus as evidenced from weathering rates of olivine. *Science Advances*, *6*(1), eaax7445. https://doi.org/10.1126/sciadv.aax7445

Garvin, J. B., Getty, S. A., Arney, G. N., Johnson, N. M., Kohler, E., Schwer, K. O., et al. (2022). Revealing the mysteries of Venus: The DAVINCI mission. *The Planetary Science Journal*, *3*(5), 117. https://doi.org/10.3847/PSJ/ac63c2

Ghail, R., Wilson, C., Widemann, T., Titov, D., Ansan, V., Bovolo, F., et al. (2020). The science goals of the EnVision Venus orbiter mission. In *EPSC2020-599, Europlanet Science Congress 2020*.

Guest, J. E., & Stofan, E. R. (1999). A new view of the stratigraphic history of Venus. *Icarus*, *139*(1), 55–66. https://doi.org/10.1006/icar.1999.6091

Haider, S. A., Bhardwaj, A., Shanmugam, M., Goyal, S. K., Sheel, V., Pabari, J., & Prasad Karanam, D. (2018). Indian Mars and Venus missions: Science and exploration. In *Paper presented at 42nd COSPAR Scientific Assembly* (Vol. *42*). Abstract id. B4.1-10-18.

Ivanov, M. A., & Head, J. W. (2011). Global geological map of Venus. *Planetary and Space Science*, *59*(13), 1559–1600. https://doi.org/10.1016/j.pss.2011.07.008

López, I., D'Incecco, P., Filiberto, J., & Komtasu, G. (2022). The volcanology of Idunn Mons, Venus: The complex evolution of a possible active volcano. *Journal of Volcanology and Geothermal Research*, *421*, 107428. https://doi.org/10.1016/j.jvolgeores.2021.107428

Lorenz, R. D., Crisp, D., & Huber, L. (2018). Venus atmospheric structure and dynamics from the VEGA lander and balloons: New results and PDS archive. *Icarus*, *305*, 277–283. https://doi.org/10.1016/j.icarus.2017.12.044

O'Rourke, J. G., Wolf, A. S., & Ehlmann, B. L. (2014). Venus: Interpreting the spatial distribution of volcanically modified craters. *Geophysical Research Letters*, *41*(23), 8252–8260. https://doi.org/10.1002/2014GL062121

Pettengill, G. H., Ford, P. G., & Wilt, R. J. (1992). Venus surface radiothermal emission as observed by Magellan. *Journal of Geophysical Research*, *97*(E8), 13091–13102. https://doi.org/10.1029/92JE01356

Phillips, R. J., Raubertas, R. F., Arvidson, R. E., Sarkar, I. C., Herrick, R. R., Izenberg, N., & Grimm, R. E. (1992). Impact craters and Venus resurfacing history. *Journal of Geophysical Research*, *97*(E10), 15923–15948. https://doi.org/10.1029/92JE01696

Romeo, I., & Turcotte, D. L. (2010). Resurfacing on Venus. *Planetary and Space Science*, *58*(10), 1374–1380. https://doi.org/10.1016/j.pss.2010.05.022

Schaber, G. G., Strom, R. G., Moore, H. J., Soderblom, L. A., Kirk, R. L., Chadwick, D. J., et al. (1992). Geology and distribution of impact craters on Venus: What are they telling us? *Journal of Geophysical Research*, *97*(E8), 13257–13301. https://doi.org/10.1029/92JE01246

Seiff, A. (1987). Further information on structure of the atmosphere of Venus derived from the VEGA Venus balloon and lander mission. *Advances in Space Research*, *7*(12), 323–328. https://doi.org/10.1016/0273-1177(87)90239-0

Shalygin, E. V., Markiewicz, W. J., Basilevsky, A. T., Titov, D. V., Ignatiev, N. I., & Head, J. W. (2015). Active volcanism on Venus in the Ganiki Chasma rift zone. *Geophysical Research Letters*, *42*(12), 4762–4769. https://doi.org/10.1002/2015GL064088

Smrekar, S. E., Dyar, D., Helbert, J., Hensley, S., Nunes, D., & Whitten, J. (2020). VERITAS (Venus Emissivity, Radio Science, InSAR, Topography and Spectroscopy): A proposed discovery mission. In *Europlanet Science Congress 2020*. https://doi.org/10.5194/epsc2020-447

Smrekar, S. E., Stofan, E. R., Mueller, N., Treiman, A., Elkins-Tanton, L., Helbert, J., et al. (2010). Recent hotspot volcanism on Venus from VIRTIS emissivity data. *Science*, *328*(5978), 605–608. https://doi.org/10.1126/science.1186785

Sundararajan, V. (2021). *Tradespace Exploration of Space System Architecture and Design for India's Shukrayaan-1, Venus Orbiter Mission*. *ASCEND 2021 Forum. Las Vegas, Navada and Virtual*. American Institute of Aeronautics and Astronautics.

Wang, C., Song, T., Shi, P., Li, M., & Fan, Q. (2022). China's Space Science Program (2025–2030): Strategic Priority Program on Space Science (III). *Chinese Journal of Space Science*, *42*(4), 514–518.

Weller, M. B., & Kiefer, W. S. (2020). The physics of changing tectonic regimes: Implications for the temporal evolution of mantle convection and the thermal history of Venus. *Journal of Geophysical Research: Planets*, *125*(1), e2019JE005960. https://doi.org/10.1029/2019JE005960

Zasova, L. V., Gorinov, D. A., Eismont, N. A., Kovalenko, I. D., Abbakumov, A. S., & Bober, S. A. (2019). Venera-D: A design of an automatic space station for Venus exploration. *Solar System Research*, *53*(7), 506–510. https://doi.org/10.1134/S0038094619070244

Zolotov, M. (2019). Chemical weathering on Venus. *Oxford Research Encyclopedia of Planetary Science*.