

NUMERICAL INVESTIGATION OF MERCURY-BEARING MINERALS TO ADDRESS THE LOW EMISSIVITY ANOMALY ON THE HIGHLANDS OF VENUS. S. T. Port¹ and V. F. Chevrier², ¹NASA Glenn Research Center, 21000 Brookpark Road, Cleveland, OH 44135 (sara.port@nasa.gov), ²University of Arkansas, 332 N. Arkansas Ave., Fayetteville, AR 72701.

Introduction: The majority of the surface of Venus is believed to be composed of basalt with a bulk relative dielectric constant of approximately $\epsilon \approx 5$ [1-2]. However, many highlands of Venus exhibit an unusual decrease in emissivity at higher elevations. The source of this anomaly may be attributed to a mineral with a dielectric constant higher than the surrounding lowlands [1-2].

Although several low emissivity patterns are observed on Venus, they can be divided into two major groups [3-5]. The first group is characterized by a sudden decrease in emissivity between 6053-6055 km (mean planetary radius = 6051.8 km) with some regions experiencing an increase in emissivity at higher elevations. Meanwhile the second pattern is observed as a decrease in emissivity above 6055 km [4-5]. The former pattern is indicative of a ferroelectric mineral where the dielectric constant increases at its Curie temperature, while the latter may signify a semiconducting mineral [3-5].

Numerous semiconducting minerals have been postulated to explain the latter low emissivity signal including pyrite, pyrrhotite, tellurium, galena, and bismuth tellurides and sulfides [2-3,6-9]. Recently, HgTe (coloradoite) has been added to the potential candidate list [10] and has been cited in several papers [1,3,8,10-12]. However, with the exception of the experiments completed by [8,10], no other studies on the stability of HgTe at Venus conditions have been completed. This study sought to numerically model the ability of HgTe, and other Hg-bearing minerals, to deposit onto the highlands of Venus.

Methods: Our calculations were completed using the Gibbs free energy minimization modeling software Thermo-Calc, and their *ssub6* thermodynamic database. A simple atmosphere with CO₂, N₂, SO₂, H₂O, CO, OCS, HF, and HCl was used for this study. All abundances were taken from [13]’s Table 1 with the exception of OCS where we used 27 ppm. This was chosen because thermochemical equilibria calculations have indicated that OCS abundances in the near surface environment may be higher than the measured value of 4.4 ± 1 ppmv at 33 km [13-16]. The volatile elements incorporated into this model were mercury (Hg), tellurium (Te), and selenium (Se). Selenium was added since, like tellurium, it is a chalcogen, and Se is more abundant than Te in basalt on Earth. Furthermore, Hg and Se can form HgSe, a mineral

with a static dielectric constant of 25.6, which is higher than HgTe’s 21 [17]. To calculate the input abundances of these three elements we used the same ratio as [7] where the abundances are correlated to sulfur:

$$A_i = n_i \times \frac{AS}{ns}$$

Here i represents element i , S represents sulfur, “ n_i is the molar abundance of element i in the terrestrial oceanic crust, and A_i is the atomic abundance of element i in ppmv in the Venusian atmosphere” [7].

The temperature/pressure profile we used was from the Venus International Reference Atmosphere (VIRA) where $z=0$ is the planetary radius of 6052 km [18]. We adjusted the abundances of Hg, Te, and Se until a Hg-bearing mineral condensed at 4 km in altitude. This is the approximate altitude where the emissivity decreases on Maxwell Montes, whose low emissivity signal is theorized to be due to a semiconducting mineral.

Results:

Hg: In our first study we omitted Te and Se and only incorporated Hg. We began with Hg = 90 ppb, which is its approximate abundance in basalt on Earth [19]. In this scenario HgS condensed at 34.4 km. If Hg = 9120 ppb, the abundance found in basaltic meteorites [20], HgS would condense at 24.5 km. Our calculations indicated that in order for HgS to condense at the temperature/pressure conditions present at 4 km, the crustal abundance of Hg must be 13386 ppm (~0.2% of the Venus atmosphere).

Hg and Te: In our next simulation we only incorporated Hg and Te. Our initial abundance for Te was set to 3 ppb because this is its approximate abundance in the oceanic crust on Earth [21]. When Hg’s abundance was set to 9120 ppb, HgTe never condensed on Venus. When Hg was increased to 13386 ppm, HgS condensed at 4 km and HgTe condensed at 12.7 km. Our model indicated that $n_i = 250$ ppb of Te is necessary for HgTe to condense at 4 km.

Hg and Se: In this simulation we only incorporated Hg and Se. Se was set to 160 ppb since this is its abundance in the oceanic crust on Earth [21]. When Hg was set to 9120 ppb, HgSe did not condense until 23.1 km. When Hg was increased to 13386 ppm, HgSe condensed at 0.41 km. In order for HgSe to condense

at 4 km, Hg needed to be decreased to 5830 ppm or Se needed to be decreased to 52 ppb.

Hg, Te, and Se: In our last simulation we incorporated all three elements of interest to the model. The initial abundances we used were Hg = 9120 ppb, Te = 3 ppb, and Se = 160 ppb. As expected, HgTe never deposited, HgSe deposited at 23.1 km, and HgS deposited at 24.6 km. Next we incorporated the abundances obtained in the previous simulations that led to deposition at 4 km: Hg = 13386 ppm, Te = 250 ppb, and Se = 52 ppb. However, instead of HgS, HgTe, and HgSe depositing at 4 km, HgS stabilized at 4.1 km, HgTe stabilized at 4.2 km and HgSe stabilized at 4.7 km. The starting altitude of their formation was decreased to 4 km by making slight modifications to the abundances. In order for HgS to form at 4 km, Hg needed to be increased to 13400 ppm. For HgTe to deposit at 4 km either Te needed to be increased to 266 ppb or Hg needed to be increased to 13822 ppm. Lastly, to get HgSe to form at 4 km either Se needed to be increased to 71 ppb or Hg needed to be increased to 15872 ppm.

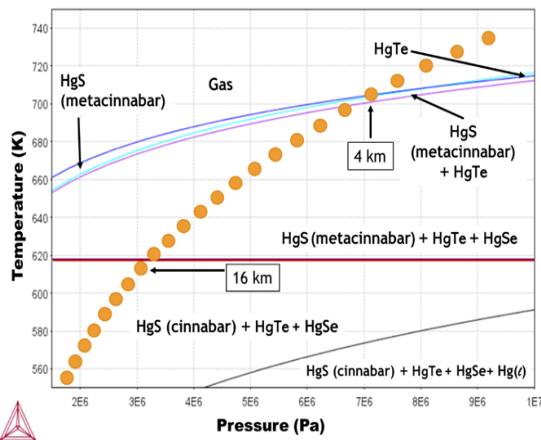


Figure 1: Phase diagram of HgS, HgTe, and HgSe where Hg=13386 ppm, Te=250 ppb, and Se=52 ppb. Orange circles represent different altitudes on Venus.

Conclusion: Our results indicate that Hg is the limiting factor for all the investigated Hg-bearing minerals in this project. Assuming Hg is plentiful on Venus (≥ 13386 ppm in the crust), the abundance of Te would need to be ~ 100 times the abundance in basalt on Earth to produce HgTe. Assuming similar Se abundances to Earth, HgSe was able to condense in the highlands, but only when Hg was initially set to 5830 ppm.

The large abundance of Hg necessary to form the investigated minerals is unlikely to be present on Venus. Measurements on the composition of the

atmosphere obtained by Venera 12 concluded that $X_{\text{Hg}} < 10^{-8}$ (the sensitivity limit of the instrument) [22]. Comparing this value with Earth yields approximately 3.5 orders of magnitude less Hg on Venus than Earth and may be attributed to Hg depletion on Venus [7, 22]. Alternatively, it may also be possible that outgassing is less efficient on Venus and perhaps more Hg is trapped within Venus [7]. However even in the latter scenario the abundance necessary for Hg-minerals to deposit is greater than six orders of magnitude more than present in basaltic rocks on Earth.

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References: [1] Gilmore et al., (2017) *Space Sci. Rev.*, 212, 1511–1540 [2] Pettengill, G.H., et al., (1988) *J. Geophys. Res.*, 93, 14,881–14,892. [3] Treiman, A., Harrington, E., Sharpton, V. (2016) *Icarus*, 280, 172–182 [4] Brossier, J., Gilmore, M. S., and Toner, K. (2020) *Icarus*, 343, 113693 [5] Brossier, J. and Gilmore, M. S. (2021) *Icarus*, 355, 114161 [6] Pettengill, G.H., et al., (1996), *Science*, 272, 1628–1631 [7] Schaefer, L. and Fegley Jr., B. (2004) *Geophys. Res. Letters*, 21, 469–472. [8] Kohler, E. (2016) Theses and Dissertations U. Arkansas, 1473. [9] Klose, K. B., Wood J. A., and Hashimoto, A. (1992) *J. Geophys. Res.*, 97, 16353–16369 [10] Kohler, E., et al., (2013) *LPSC XLIV*, Abstract #2951. [11] Taylor, F. W., Svedhem, H., Head, J. W. (2018) *Space Sci. Rev.*, 214 [12] Berger, G. et al., (2019) *Icarus*, 329, 8–23 [13] Zolotov M.Y. (2018) *Rev. Mineral. Geochem.*, 84, 351–391. [14] Krasnopolsky, V. A. and Pollack, J. B. (1994) *Icarus*, 109, 58–78 [15] Krasnopolsky, V.A. (2007) *Icarus*, 91, 25–37. [16] Zolotov, M. Yu. (1996) *Geochem. Int.*, 33, 80–100 [17] Adachi, S. (2004) *Springer*, 419–472 [18] Seiff, A., et al., (1985) *Adv. Space Res.*, 5, 3–58. [19] Faure, G. (1998) *Prentice Hall*, 514–515. [20] Kitts, K. and Lodders, K. (1998) *Meteorit. Planet. Sci.*, 33, A197–A213 [21] Lodders, K. and Fegley, B. (1998) *Oxford University Press*, 140–142. [22] Barsukov, V. L., et al., (1981) *Proc. Lunar Planet. Sci.*, 1517–1532