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The volatile evolution of Venus from Late Accretion to present-day.

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Abstract

We use numerical simulations to study the bulk atmospheric content evolution over the 4.5 Gyr of the history of Venus, from the Late Accretion up to present-day. We consider volatile exchanges on the global scale. Multiple mechanisms are included in the study, such as all types of atmospheric escape processes, volcanic degassing and mantle dynamics, surface alteration, impact erosion, delivery and melting of the surface and mantle. We investigate the relative importance of those mechanisms for the long term evolution of Venus and their interactions. We show that Venus is unlikely to have possessed a very large amount of water in its atmosphere for most of its evolution. Only during Late Accretion would this amount be significant and even then, it implies that i) Late Accretion was mostly dry and ii) putative water oceans on Venus were limited to less than a fraction of an Earth Ocean.

1. Introduction

With the eye of the scientific community turning back toward Venus and new missions being prepared, the question of the evolution of surface conditions on Venus has gathered considerable interest [2, 3]. Due to both the striking similarities and the obvious differences between Earth and Venus, understanding Venus might hold some of the keys to how planets become habitable. It has thus been suggested that Venus could have had liquid water oceans for part of its evolution, starting right after the magma ocean phase, depending on initial and atmospheric conditions. Those studies focus rightly on liquid water stability but neglect the fate of water and volatile: how they were brought to the atmosphere and what they became after the ocean disappeared when the planet evolved and reached its present-day situation. We look at the same issue with this later perspective in mind and set limits to how much volatiles and water in particular can be exchanged through various mechanisms during the long-term evolution of Venus up to present-day.

2. Modeling Venus' evolution

We have been developing a coupled numerical simulation of the evolution of Venus [1], striving to identify and model mechanisms that are important to the behavior of the planet and its surface conditions. Currently the simulations include modeling of mantle dynamics, core evolution (magnetic field generation), volcanism, surface alteration, atmospheric escape (both hydrodynamic and non-thermal), evolution of atmosphere composition, and evolution of surface conditions (greenhouse effect) and the coupling between interior and atmosphere of the planet. We have also modeled the effects of large meteoritic impacts on long term evolution through three aspects: atmosphere erosion, volatile delivery and mantle dynamics perturbation due to energy deposition. Of particular interest are the limits to the volatile exchanges set by present-day observation: we reject any scenario that deviates far from present-day Venus at the end of its simulated history.

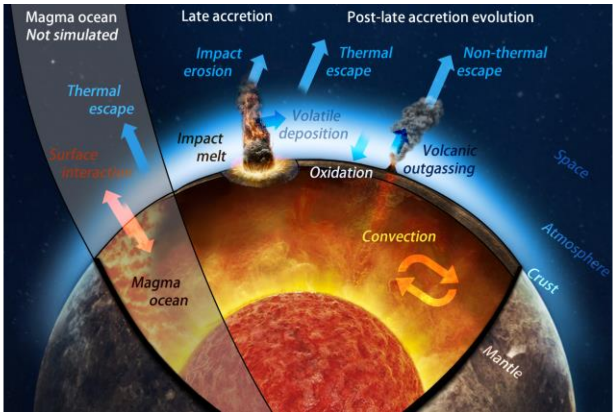

Figure 1: Venus evolution from the point of view of volatile exchanges, including all mechanisms considered here.

3. Results

Volatile fluxes between the different layers of the planet seem critical to estimate how Venus changed over time. This is especially important as we have highlighted the strong role played by mantle/atmosphere coupling in regulating both mantle dynamics and surface conditions through surface temperature evolution. Mantle convection regime evolves with time and depends on surface conditions. We produce scenarios that fit present-day conditions and feature both early mobile lid regime (akin to plate tectonics) as well as late episodic lid regime with resurfacing events. The early history of Venus, in particular, seems to have large repercussions on its long term evolution and present-day state, as it determines volatile inventories and repartition.

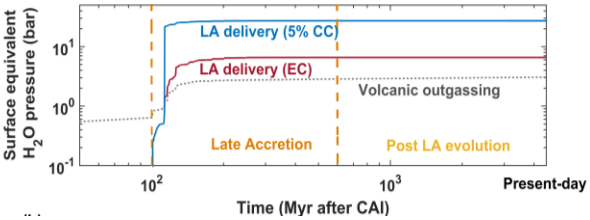

Figure 2: Relative importance of volcanic outgassing of Water and impact delivery during Late Accretion depending on impactor composition.

It is therefore critical to investigate impacts that affect the evolution of Venus during the Late Accretion era. While the atmosphere erosion they generate doesn't deplete the atmosphere as much as swarms of smaller bodies, they instead act as a significant source of volatiles. Indeed, if Late Accretion is mainly composed of volatile-rich bodies, it is very difficult to reach the observed present-day state of Venus; instead the atmosphere may become too wet. Simulations show wet material (carbon chondrites) contribution limit at a maximum of 5-10% (mass.) of the total accreted mass during Late Accretion (the larger portion of the Late accretion being composed of enstatite chondrite bodies). Large impacts also affect mantle convection, modifying convection patterns for millions of years. Finally, the more energetic collisions (impactors with radii in the 100s of km, high velocity) generate massive melting events near impact location, associated with large scale degassing of the mantle. This leads to mantle depletion and can potentially leave (at least) the upper mantle of the planet dry, with strong consequences for later evolution.

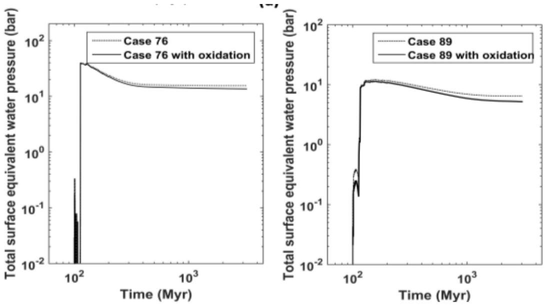

Figure 3 : Relative importance of surface alteration processes in the global evolution the atmosphere of Venus. Left: high escape. Right: low escape.

4. Conclusions

Impact delivery has the potential to be the major source of volatiles for both the interior and the atmosphere of a terrestrial planet like Venus. However, given the present-day observation, this delivery flux has been limited by very low volatile concentrations in the impactors, akin to enstatite chondrite bodies. Higher delivery of volatiles is incompatible with the dry and devoid of oxygen present-day atmosphere. Other mechanisms represent relatively minor contributions to the early evolution (4.5-3.5 Gyr ago) but are likely to govern later history. The limitation to the capacity of Venus to remove water and oxygen from its atmosphere means it is more and more difficult to accommodate water oceans at the surface as time passes. Instead, during the last 4 Gyr, a maximum of 2 bar water could have stayed in the atmosphere, most of it more than 3 Gyr ago, corresponding to no more than a 20 m global equivalent layer of liquid water. Earlier oceans could have been somewhat larger but no more than 0.1 Earth Oceans.

References

[1] Gillmann, C., Golabek, G. J. and Tackley, P. J.: Effect of a single large impact on the coupled atmosphere-interior evolution of Venus. Icarus 268, 2016.

[2] Salvador, A., et al.: The relative influence of H_2O and CO_2 on the primitive surface conditions and evolution of rocky planets. J. Geophys. Res. 122, 1458–1486, 2017.

[3] Way, M. J., et al. Was Venus the first habitable world of our solar system? Geophys. Res. Lett. 43, 8376–8383 (2016).