EPSC Abstracts
Vol. 11, EPSC2017-15, 2017
European Planetary Science Congress 2017

The role of Late Veneer impacts in the evolution of Venus

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Abstract

Our main interest is to understand how different mechanisms contribute to changes in long term evolution. In particular, the primitive history (the first Gy) of terrestrial planets is heavily influenced by collisions. We investigate how the coupled evolution of Venus' atmosphere and mantle is modified by those impacts. We focus on volatile fluxes: atmospheric escape and mantle degassing. We link those processes into a coupled model of mantle convection and atmospheric evolution. Feedback of the atmosphere on the mantle is included. As large impacts are capable of contributing to atmospheric escape, volatile replenishment and energy transfer, we estimate their effects on the evolution of Venus.

1. Introduction

Meteoritic impacts are instant processes that have lasting effects on the long term evolution of terrestrial planets. Collisions affect both the solid part of the planet and its atmosphere in complex ways that need to be quantified. The study of surface conditions and what makes a planet habitable is especially sensitive to small variations and requires a more complete modeling of interactions than parameterized models are able to provide.

1.1 General Model

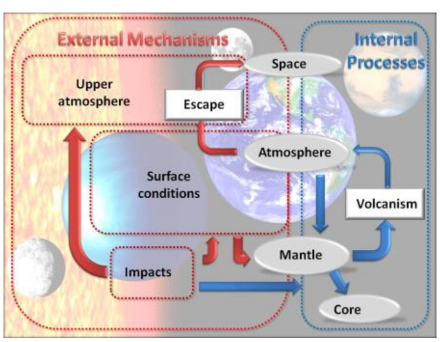

Figure 1: basic layout of the model.

(i) Internal processes are dependent on mantle dynamics. We use a variation of the StagYY code designed for Venus [1]. Physical are depth-dependent. The phase transitions in the olivine system and in the pyroxene-garnet system are included. The assumed rheology is Newtonian diffusion creep plus plastic yielding. Degassing is calculated when melting occurs and we use a wide range of possible lava compositions.

(ii) Atmospheric escape modeling involves two different aspects: hydrodynamic escape (0-500 Myr) and non-thermal escape mechanisms (dominant post 4 Ga). Hydrodynamic escape is the massive outflow of light volatiles into space occurring when solar Extreme UV is strong. Post 4 Ga escape from non-thermal processes is comparatively low. Mechanisms include sputtering, ion pick-up, plasma clouds and dissociative recombination. Constraints include present-day measurements by the ASPERA instrument and numerical simulations.

(iii) Surface conditions are calculated from the greenhouse effect of main gases from the atmosphere: water and CO_2. We use a one-dimensional radiative-convective grey atmosphere model modified from [2]. Surface temperature is calculated and used as a boundary condition for the mantle, creating a feedback between mantle and the atmosphere.

1.2 Impacts

Impacts have three main effects on terrestrial planets. They can (i) bring volatiles and (ii) erode the atmosphere. Volatile deposition assumes chondritic composition and is limited by the fraction of the projectile that is not accreted or that doesn't melt. Atmosphere erosion is inferred using [3]. Mantle dynamics can also be modified by the (iii) large amount of energy brought to the mantle. A thermal anomaly is created by the impact in the mantle and can lead to melting. Collision scenarios are chosen from average and extreme numerical simulations of the Late Veneer period.

2. Results

We are able to produce simulations that are consistent with current Venus situation (atmosphere, resurfacing, volatiles, fractionation). Results linked to present-day atmosphere state are heavily dependent on escape rate and initial volatile inventory. Surface conditions depend mainly on atmosphere water content. Surface temperature has a direct influence on mantle convection with low temperatures correlated with mobile lid behavior while high ones favor stagnant or episodic lid. Mobile-lid regime is akin to plate tectonics and could be a way to inject volatiles back into the mantle.

Large impacts are shown to affect only marginally the evolution of Venus through atmosphere erosion. Single impacts don't have enough eroding power to durably affect the atmosphere and large impacts are not numerous enough. Swarms of small bodies (<50km radius) might be a better candidate for this process. Large impacts actually bring more volatiles than they blow off, at all compositions tested (fig.2).

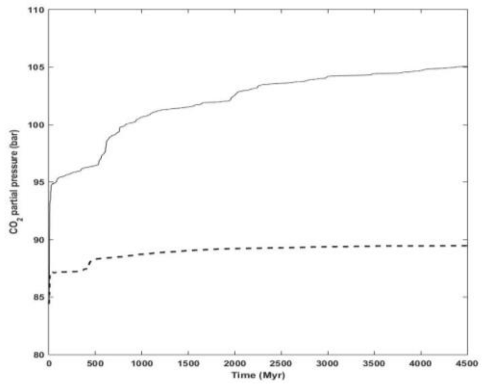

Figure 2: CO2 pressure evolution of the atmosphere of Venus. Impact delivery is taken into account for two projectile compositions: ordinary chondrite (dashed line) and carbonaceous chondrite (full line).

The amount of volatiles brought by large impactors is comparable to the amount of degassing taking place during the subsequent evolution. This occurs very early in the history of the planet and affects initial conditions of the simulations. As a volatile source, it is opposed by the high escape fluxes of early evolution (hydrodynamic escape).

A second important effect of large collisions is the thermal anomalies thus produced. When impactors are bigger than 200-300 km radius, they start to affect a deep enough portion of the mantle to have long term consequences. Anomalies tend to propagate by spreading across the surface due to the buoyancy of the hot material. Old crust is destroyed or remixed in the mantle. Impacts lead to the melting of a large part of the upper mantle leading to its depletion (fig. 3) and degassing. As we consider no process that remixes volatiles into the mantle, with enough large impacts distributed over the planet, the mantle can be efficiently depleted by more than 90% of its volatiles in the first few tens to hundreds of million years. This drastically cuts down degassing in the late history of the planet and leads to lower present-day surface temperatures.

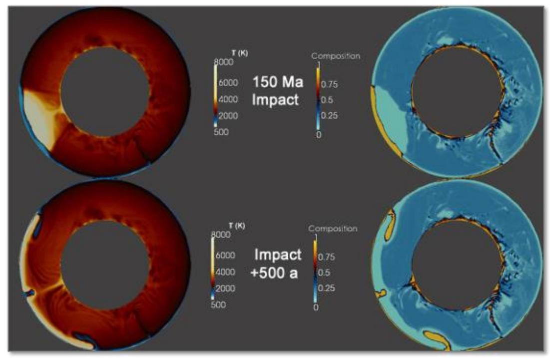

Figure 3: Mantle temperature and composition fields after a large (800km) impact. Upper mantle is mobilized and depleted.

3. Summary and Conclusions

Late Veneer impacts heavily affect initial conditions of terrestrial planets evolution, in particular regarding the volatile inventory. While they do not cause much atmosphere erosion, they release large amounts of gases and lead to widespread degassing. They can also efficiently deplete the mantle of the planet. In order to better constrain planetary evolution, it becomes essential to assess the recycling of volatiles into the mantle both during impacts and afterwards (during periods of mobile lid regime, for example).

References

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