Goldschmidt 2023 Abstract
https://doi.org/10.7185/gold2023.19517

On the Magmatic Processes Making Early Planetary Volatile Reservoirs

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This talk addresses volatile components and planetary oxidation states during the early accretion processes, involving magma ocean planetary bodies. The volatiles are distributed between the gaseous atmosphere, the silicate magma ocean and the metallic core. Laboratory-based laws are used to define the fate of CHONS elements in such a three-phase system.

I first expose a model for the oxidation state of planetary bodies, i.e. fO2, that is gauged by the ratio FeO in the mantle to Fe in metallic core, increasing in the order Mercury-Venus-Earth-Mars-Vesta. We show that planetary body oxidation states can be deduced from the proportion of the constituting chondritic materials. This approach predicts the oxidation state of Mars and Earth using the proportion enstatite-ordinary-carbonaceous chondrites independently estimated from a variety of isotopic constraints. Making Planet Earth requires less than 10 wt% CI, the rest being essentially enstatite chondrites. Mars is dominated by ordinary chondrites. Interestingly, building planetesimal Vesta (high FeO and relatively high Fe) requires another component. An H2O component is required, it might be ice.

The second section discusses the outgassing/ingassing repartition of COHNS components during magma ocean stages. This repartition is essentially controlled by fO2, that is set by the chondritic proportions, and by the planetary body sizes. The amount of C-H-S-N that is dissolved in the magma ocean increases with planetary size, yielding values that are comparable to the existing estimations of the bulk silicate Earth contents in volatiles. This suggests that impact degassing during the latest steps of accretion efficiently removed the outgassed atmospheres. Impact degassing can fractionate COHNS elements and their isotopes in way that is strongly fO2 dependent. This makes the entire accretion, degassing, core formation, impact degassing process truly predictive.

Finally, we reveal a mechanism for building deep volatile reservoirs: during the simultaneous core-mantle-atmosphere differentiation, gas bubbles are preferentially attached to metal drops. This implies that small metal droplets attached to large gas bubbles can float in the magma ocean and that small gas bubbles attached to large metal drops can sink down to the core-mantle boundary. This enables the formation of deep primordial volatile reservoirs upon magma ocean solidification.