Collisions among porous planetesimals and the water content of planetary embryos

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N-body simulations of planet formation have advanced in recent years to predict the bulk composition of the final products as well as their orbital properties. Such studies (e.g. [1]) track the provenance of each planetary building block, and based on an assumed initial compositional gradient for the planetesimals and embryos with distance from the star, the final compositions of the planets are determined as being the sum of each of its individual components. It is generally found that planets that form in what are assumed to be initially 'dry' regions are often able to acquire significant amounts of water through the accretion of planetesimals that originate much further from the star. Often, these models predict very water-rich worlds, sometimes in disagreement with the current inventory of water in our terrestrial planets.

Recently, it has been argued that the growth of planetary embryos proceeds not by direct accretion of planetesimals, but rather by the accretion of fragments produced during planetesimal collisions [2]. In fact, planetesimals are more likely to be destroyed in collisions with one another than by direct accretion by a growing embryo. The orbits of collision fragments are then circularized by the gas in a protoplanetary disk, allowing them to easily be accreted by embryos.

We have developed a model to examine high-velocity impacts between planetesimals [3]. We find that if young planetesimals were porous, which is expected given the low velocity collisions by which these objects accrete, shock heating in subsequent high-velocity, disruptive collisions can lead to temperature increases of the fragments by hundreds of Kelvin, which would drive off volatiles such as water. Embryos that formed from those heated and dried fragments would be volatile-depleted compared to current accretion models, and may reconcile the discrepancy between those model predictions and the actual water abundance of Earth.

[1] O'Brien *et al.* (2006) *Icarus* **184**, 39-58. [2] Chambers (2006) *Icarus* **180**, 496-513. [3] Davison *et al.* (2008) *LPSC* abstract #2008.

Volcanic SO_2, atmospheric photochemistry, and climate on early Mars

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Small terrestrial planets, such as Mars, have significant problems in maintaining habitablity. One major hurdle presented by the lower Martian gravity is that significant volcanic outgassing is required to form a dense atmosphere, a seeming necessity for clement conditions. Despite the widely-held hypothesis that there were oceans on early Mars, no self-consistent climate scheme has yet been shown to be fully compatible with this hypothesis [1].

Recently, an SO_2-based geochemical cycle has been proposed for early Mars [2, 4]. SO_2 is undoubtedly a good greenhouse gas, provided that it can be photochemically and geochemically stabilized, and provided that the formation of reflective sulfate aerosols, which are known to act as powerful coolants on Earth and Venus, can be suppressed. We will show results from two modeling studies which cast doubt on the ability of SO_2 to act as a warming agent for terrestrial planets.

First, we describe an extension to a recent 1D photochemical model for the Martian atmosphere [6]. We expand this model to include sulfur chemistry including the formation of sulfate/polysulfur aerosols, along with self-consistent radiative transfer with aerosol mie-scattering. We show that enhanced volcanic sulfur fluxes drive the Martian atmosphere to a more reduced state. In our most reducing Martian atmospheres, SO_2 persits in the gas phase, but it is very difficult to maintain partial pressures greater than ~1 ppm. Furthermore, these atmospheres also feature significant sulfate aerosol formation. We next describe results from a 1D radiative-convective climate model [3], which we have modified to account for sulfate aerosols. Using the atmospheric profiles created by the photochemical model, we show that the net effect of enhanced sulfur fluxes to the Martian atmosphere is likely to be net cooling, not warming, due to the anti-greenhouse effect of the sulfate aerosols.

[1] Haberle (1998) *J.Geophys.Res.* **103**(E12). [2] Halevy, Zuber & Schrag (2007) *Science* **318**, 1903-1907. [3] Haqq-Misra *et al*. (2008). *Astrobiology*. **8** (6) 1-11. [4] Johnson *et al*. (2008) *J. Geophys.Res.* **113**(E8). [5] Tian, Kasting & Solomon (2008) *Science*, submitted. [6] Zahnle *et al*. (2008) *J. Geophys. Res.*, **113**(E11).