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Modelling planetary accretion with sliding redox conditions during metal-silicate-gas equilibria

FABRICE GAILLARD[1], YVES MARROCCHI[2], ALI BOUHIFD[3], MATHIEU ROSKOSZ[4] AND GREGORY ROGERIE[5]

[1]ISTO - CNRS
[2]CRPG, CNRS-Université de Lorraine
[3]CNRS, Laboratoire Magmas et Volcans
[4]IMPMC, Muséum National d'Histoire Naturelle, Sorbonne Université, CNRS UMR 7590 (Paris)
[5]ISTO

Two mechanisms of planetary accretion are usually discussed: Pebble accretion describes an equilibrium, continuous and rapid growth from small to larger bodies vs. the collisional growth involving stochastic, out-of-equilibrium and energetic impacts between embryos, planetesimals and planets. We work on the equilibrium growth mechanism, deploying a new generation of thermochemical models resolving multicomponent equilibria in the triphasic system prevailing during planetary differentiation, metal-silicate-gas. This modelling defines a sort of chemical baseline that can be interrupted at any stages by out-of-equilibrium collisions.

Here, we resolve the chemical speciation and phase proportion in a system that is closed to oxygen. This enables prediction, rather than assumption of the oxygen fugacity during accretion. This determinist approach of the redox evolution during planetary accretion enables planetary oxidation state (FeO-Fe proportion in a bulk planet) to be related to the nature and provenance of the accreting materials. Here, we used this new generation of model to relate the Mercury-Venus-Earth-Mars-Vesta planetary suite, which is characterized by large variations in oxidation state as defined by the Fe to FeO ratio (i.e. core to silicate ratio), to the nature of the chondritic materials involved in their construction.

We show that Mars oxidation state can be explained by the accretion of nearly 100% of ordinary chondrites. This fits the Martian mantle FeO, and both size and composition of its core. We show further tests revealing that the proportion of enstatite chondrites or the fraction of C-H organic compounds present in the ordinary chondrites at the timing of accretion has a direct and measurable effect on the planetary oxidation state.

Similar tests are done to explain Vesta. Vesta's oxidation state is consistent with the accretion of carbonaceous materials, but this conflicts with isotope data suggesting the predominance of non-carbonaceous materials. We present numerical tests relating the presence of water versus organic materials to vesta's oxidation state, which speaks for the accretion water-bearing materials being responsible for the high Vestian oxidation state. H2O is then lost by degassing from Vesta's magma ocean.

Several qualitative perspectives on how such model can make predictions for Earth-size or superEarth-size bodies is then discussed.