Cataclysmic reduction of terrestrial planets

For Nature or Science

*Submission goal: before end of 2020*

Mercury, and presumably other bodies in our galaxy, has a relatively oversized core compared to the entirety of its mass. Two key formation scenarios have been proposed to explain this enlarged core. The current and most favored of these is that, due to Mercury’s proximity to the sun, we should expect Mercury to have formed from quite reduced primordial materials. Since reduced materials may go into a metallic phase (e.g., Fe over FeO), the reduced nature of the planet resulted in the differentiation of a large core. It has been observed that Mercury’s composition is extremely reducing, and so this hypothesis has gained favor in the community.

A second hypothesis has also been proposed, wherein a larger body accreted and formed a more typically sized core (relative to its overall mass). This body was then struck by a giant impact, causing the shedding off of much of its silicate material. Thus, what was left behind was the original planetary core surrounded by a relatively thin mantle/crust shell.

This process might also lead to a reduced body, consistent with what we observe at modern Mercury. The originally accreted core would have formed at relatively high pressure, such that a significant proportion of Si could be dissolved in the core as metallic Si. Once much of the silicate outer shell was removed, the core (and overlying mantle) would then re-equilibrate at a much lower pressure. Much of the metallic Si would suddenly be unstable and would react with the silicate mantle to form SiO2, enriching the silicate in Si and causing the rainout of FeO as metallic Fe. In other words, there would be an exchange between metallic Si in the core and oxidized FeO in the mantle. This would have the result of lowering the fO2 of the body.

If this process is thermodynamically feasible, this suggests that we should not discount the giant impact hypothesis as a potential Mercurian origin store. Moreover, this process might occur elsewhere in the universe, suggesting a much wider range of potential fO2s throughout exoplanetary systems (e.g., not necessarily tied only to planet-star distance) than is currently though to exist.

**Methodology**

This paper seeks to create an all-encompassing model of Si solubility in Fe-rich metals as a function of P, T, and fO2. Some models of this sort exist in the literature, but none have datasets as exhaustive as the one we are currently building.

With this model, we can answer key questions such as: What fO2 change is expected with a pressure reduction due to the loss of mass from a giant impact event? Mercury will not be the focus of this discussion but will serve as a local case study.

**Some requirements for modeling**

1. An internally consistent method to calculate fO2, rather than relying on the values reported in literature.
   1. We suggest using the Fe + 1/2O2 -> FeO reaction, with appropriate activity coefficients for FeO in the silicate liquid (based on melt composition) and the appropriate activity values for Fe in metal.
2. Preferably, the model would be regressed based on thermodynamic properties rather than empirically.
3. This model should be automated (e.g., with Python and pandas)
4. Should have the ability to specify one of multiple activity models, if possible, such that the model could be run with any model available, and we can assess how this changes the results.

**Other angles necessary to explore/think on in the paper**

1. Kinetics and timescales
   1. Our thermodynamic equilibrium model can calculate the relevant end-member states of the system, but is there sufficient time for this process to occur in nature?
   2. John working on this.
2. Planetary dynamics
   1. Certain conditions (e.g., grain size of the mantle) must be met such that the silicate mantle of a planet could be effectively removed and not simply reaccreted.
   2. Steve Desch will be consulted on this.

**Some potential key figures**

1. Si concentration in metal vs fO2, with one curve for each of a handful of pressures.
   1. Illustrate the importance of P on fO2 and metallic Si stability
   2. T and X also play a role, so could consider other figures to go along with this one.

**Important reactions**

SiO2melt 🡪 Simelt + O2

Femetal + 1/2O2 🡪 FeOmelt