

Outstanding issues with respect to the timing of differentiation and mantle oxidation: a comparative planetary perspective – Earth, Mars and 4 Vesta. K. Righter¹, ¹NASA Johnson Space Center, Mailcode KT, 2101 NASA Pkwy., Houston, TX 77058; kevin.righter-1@nasa.gov.

Introduction: Detailed chronologic and petrologic information available for Earth, Mars and Vesta reveal several outstanding problems concerning our understanding of their formation. This contribution aims to define what we know for each body, compare the similarities and differences and suggest future pathways for resolution. In particular, focus will be on the timing and mechanisms for mantle oxidation.

4 Vesta: The HED clan of achondrites is most likely from asteroid 4 Vesta or a similar differentiated body [1]. As such we have samples of a small, dry, ancient planetesimal in our collections. This small body should have a straightforward explanation given the simple array of factors controlling its formation. Nonetheless, many aspects remain elusive. A satisfactory explanation for depletion of volatile elements in the HED parent body/Vesta does not yet exist. New timing constraints on the differentiation of the HED parent body have requiring re-thinking the origin of the body. Petrogenetic scenarios are based on just a few low pressure phase equilibria; more experimental constraints would be useful. Recent discoveries have shown that there may be multiple parent bodies for the HED clan. And finally, the origin of this small body cannot be modeled adequately, even despite its simplicity; a model that includes metal and silicate together is not yet available. Clearly there are many aspects to the origin and evolution of the HED parent body that remain to be studied.

With respect to mantle oxidation state, we have a conundrum that core formation models result in conditions of IW-2.5, but basalt melting models require conditions of IW-1. When and how did the oxidation take place?

Mars

Based on studies of Martian meteorites, we know that Mars differentiated early, faster than Earth, but slower than Vesta. And we also know that the meteorites record evidence of several Martian interior reservoirs [2].

Calculations of fO_2 in the Martian meteorites result in a 5 log fO_2 unit range in values relative to the FMQ buffer (Fig. 1). In the absence of plate tectonics and recycling mechanisms, oxidation of the mantle is difficult to explain. However, if graphite is present in a planetary mantle, the effect of pressure on C-CO-CO₂-CH₄ equilibria is such that oxygen fugacity would

become very high as pressure increases. Given the range of fO_2 estimates for martian meteorites, it is worthwhile considering whether this could be achieved by polybaric C-CO-CO₂-CH₄ equilibria in the martian mantle. Only 40-80 ppm C is required to keep peridotite mantle buffered at the C-O surface. Indeed, studies of Martian meteorites have shown that Mars is a volatile-rich planet, and C may be an important constituent of the volatile budget. If C buffering at variable pressure is controlling oxygen fugacity in the Martian mantle, it would require formation of ALH84001 at lowest pressures, shergottites at intermediate pressures, and nakhlite and Chassigny parent melt formation at high pressures, all of which is consistent with what we know.

Earth: Earth accreted the slowest of all planets studied, between 20 and 45 Ma after T_0 . In addition, the terrestrial mantle is much more oxidized than the conditions at which the core separated (Fig. 1). Earth is different from Vesta and Mars in that its internal heat has provided driving energy for vigorous mantle convection and associated plate tectonic on the surface. As a result the Earth's mantle has had plenty of time and opportunity for transformation over time. No secular changes in mantle redox state have been detected, but there is ~300 Ma of missing rock record for Earth, so it is not clear on what timeframe mantle oxidation could have occurred. A recent suggestion that Earth's mantle was oxidized by the breakdown of MgFe perovskite to Fe³⁺ and Fe metal [3] is an interesting solution to this old problem, but is not without additional questions. Mars is just as oxidized as Earth (maybe even more so), but MgFe perovskite (small or non-existent in the martian mantle) is not available for oxidation in the Martian mantle.

Discussion

A viable mechanism for oxidation of the Martian mantle remains elusive; water as an oxidant is possible, but there is not much water available from the interior given what we know from Martian meteorite samples, and the stability of hydrous phases. An alternative explanation is that the Martian mantle is buffered by C-CO-CO₂ equilibria, and the broad range is caused by normal magmatic polybaric processes in the deep and shallow mantle. If this works for Mars, then why couldn't it for Earth? An elaborate MgFe

perovskite dissociation mechanism may be unnecessary for the Earth as well.

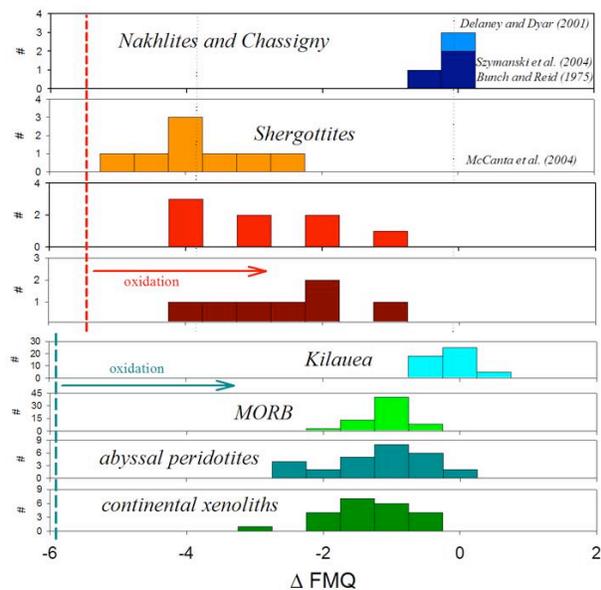


Figure 1: (Top) Histogram of Martian meteorite values of oxygen fugacity compared to the conditions proposed for Martian core formation (dashed red vertical line). (Bottom) histogram of terrestrial sample values of oxygen fugacity compared to the conditions proposed for terrestrial core formation (dashed vertical green line). A similar relation exists for samples from the HED parent body (or 4 Vesta).

References:

- [1] Drake, M.J. (2001) MAPS 36, 501.
- [2] Righter, K. (2007) 31st Antarctic Meteorite Symposium (NIPR, Tokyo) meeting abstract.
- [3] Frost, D. J. et al. (2004) Nature 428, 409–412.