

WATER IN TERRESTRIAL PLANETS: ALWAYS AN OXIDANT? K. Righter, Mail Code ST, NASA Johnson Space Center, Houston, TX 77058; kevin.righter-1@nasa.gov.

Introduction

Water is commonly assumed to be an oxidant in many planetary settings. Because it can affect Fe-FeO-Fe₂O₃ equilibria and thus bulk compositional properties of planets and asteroids, this is an important ingredient to understand. The role of water in two settings will be addressed - magmas, and mantles during accretion - along with the implications for planet growth and evolution.

Magmas

Samples from the inner solar system have a wide range of oxygen fugacity (*f*O₂), as defined by mineral-melt-gas equilibria on a variety of samples. Asteroid (meteorites) and lunar samples are the most reduced [1], whereas terrestrial samples define an enormous range of close to 10 orders of magnitude [2]. Samples from Mars are narrow in range, and relatively intermediate, falling at the low end of the terrestrial range ([3-7]; Fig. 1). Several studies have asserted that the

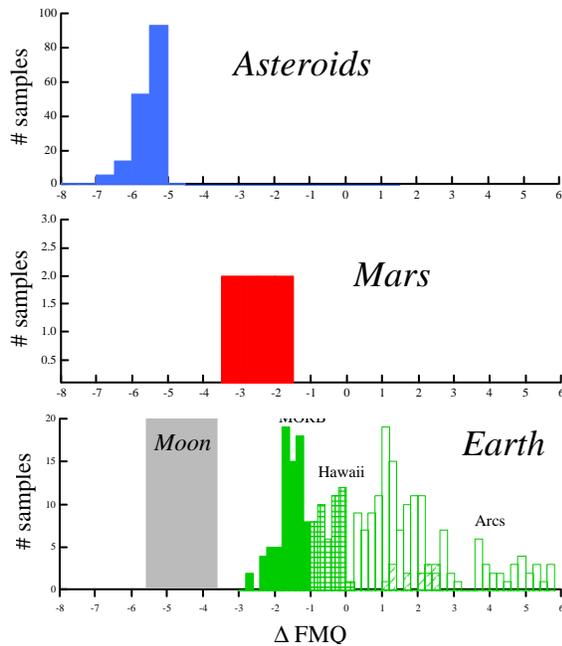
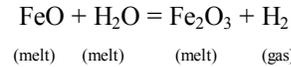


Figure 1: Histogram of Δ FMQ values (oxygen fugacity normalized to the fayalite-magnetite-quartz buffer) calculated for terrestrial, martian, lunar and meteorite samples (data from [1-7, 21]).

more oxidized samples from Mars are due to the influence of water ([7,8]), either through direct interaction with H₂O or by involvement of hydrous phases in the martian mantle. Such a reaction could be simply modelled as:



Although this is a common assertion, some constraints on the applicability of this equilibrium to magmas on Mars or Earth come from experimental studies. Because Fe₂O₃/FeO is controlled by T, *f*O₂, P and bulk composition, the effect of these variables must be well understood in a dry system before an assessment of the effect of water can be made. Moore et al. (1995) showed that the addition of up to 4 wt% water to a

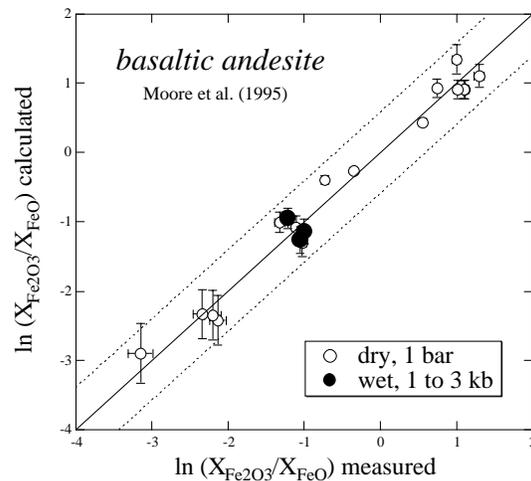


Figure 2: Comparison of measured and calculated Fe₂O₃/FeO from dry and wet (up to 3.5 wt% H₂O) experiments from [9].

basaltic andesite melt does not change the Fe₂O₃/FeO ([9]; Fig. 2). Turning to a terrestrial example for further insight, there is extensive isotopic evidence for the influence of meteoric water with the magma in the Yellowstone Plateau volcanic field, yet the Fe₂O₃/FeO remains unchanged [10].

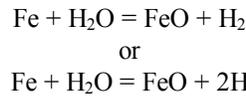
An alternative way of generating *f*O₂ differences in Martian samples may be through pressure effects caused by carbon (C-CO-CO₂) buffering [11,12]. These studies have shown that it is relatively easy to generate differences of 1 to 2 log *f*O₂ units in magmas by varying the depth at which graphite is stable or eliminated from a source region. This raises the possibility that the oxidized mantle reservoir on Mars does not require water, but rather subtle changes in pressure and carbon saturation.

Mantles

Recent work has suggested that water was present during accretion, because the isotopic character of H,

Ar and Ne in comets (the commonly asserted source of terrestrial water) is not a good match to terrestrial oceans [13,14]. If a significant amount of water was present during accretion, water would have had a large influence on all aspects of the evolution of the earliest Earth [15].

One such influence could be as an oxidant in the mantle. If water was present with iron metal, some of the latter could have been oxidized by equilibria such as:



where in the first equilibrium, H is lost to the atmosphere [16] and in the second it is lost to the core [17]. Both of these locations are possible for H, but for the purposes of this topic, the net result is that Fe is oxidized to FeO. Again, experimental experience is relevant to these equilibria. Although water dissolved in a basaltic melt oxidizes metallic iron in the experiments of [18,19], there is still water left after equilibrium has been achieved. Thus water can be an oxidant during accretion, and also remain in significant amounts in the mantle.

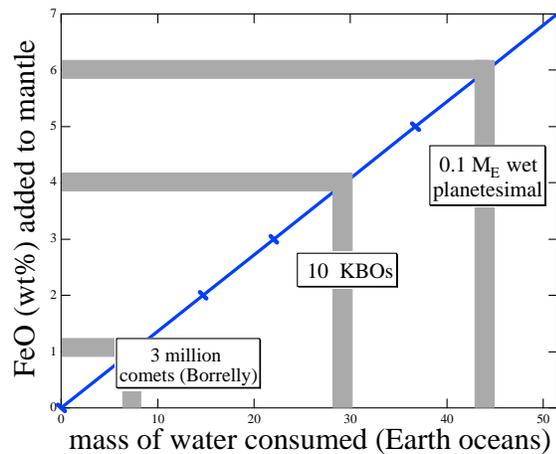


Figure 3: Plot of H₂O consumed during reaction of water with Fe to produce FeO in the mantle. Examples cited are based on physical properties described in [20] and [22].

If water is an oxidant, could Earth have accreted from more reduced materials, with FeO content of mantle set by reaction of water with Fe? If the Earth was accreted from reduced material, such as EH chondrites, how much H₂O would be required to bring FeO content from ~2% FeO (EH) to the ~8% FeO (PUM)? Addition of 6 wt% FeO to the mantle would require 3.4×10^{24} moles of water, which corresponds to approximately 45 terrestrial oceans (6×10^{25} g H₂O; Fig. 3). Although this seems like a tremendous amount of

water, it could be brought in during accretion by a number of different sources including: a) a wet planetesimal, 10% the mass of the total Earth (e.g., [22]) and containing 10% H₂O; b) comets; or c) Kuiper Belt Objects (KBO). A range of scenarios exist, depending upon how much FeO must be produced by oxidation (Fig. 3). Which specific materials can satisfy compositional and isotopic constraints remains an open question and should be one of the goals of robotic and sample return missions.

In summary, 50 oceans worth of water delivered to an early reduced Earth could have provided an oxidant to set the terrestrial mantle at 8 wt% FeO.

Summary

Water can be a very potent oxidant in some settings, but this is not universally true. Careful assessment must be made of its specific role in any given setting.

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