

PATHWAYS OF HYDROGEN GENERATION DURING AQUEOUS ALTERATION OF CHONDRITES

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Formation, phase separation, and escape of gases during aqueous alteration of asteroids affected pressure and redox conditions in their interiors [1-5]. Although formation of H₂ in asteroids has been predicted [1-4], conditions and pathways of H₂ generation have not been thoroughly explored. We review the potential for H₂ production through aqueous oxidation of Fe-Ni metal, ferrous silicates, and troilite. In the framework of these pathways, production of H₂ depends on temperature, pressure, the amount, ionic strength, pH, and oxidation state of solution; the amount, composition, and grain size of minerals, as well as on the ability of H₂ to leave the reaction zone.

The Fe⁰-H₂O(l) equilibrium cannot be attained and water-Fe⁰ interactions in asteroids proceeded until either the metal (as in CI carbonaceous chondrites), or the H₂O (as in ordinary chondrites) was exhausted. Alkaline fluids [1,4] favored formation of magnetite via reaction $3\text{Fe}^0 + 4\text{H}_2\text{O}(\text{l}) \rightarrow \text{Fe}_3\text{O}_4 + 4\text{H}_2$ (1) and an age of magnetite in the Orgueil CI chondrite [6] is consistent with rapid H₂ generation. In neutral and alkaline solutions, the pH does not affect the rate of reaction (1), but several other factors (absorption of H₂, presence of organic species, low water activity, and inability of H₂ to escape) could make the process slower. Although reaction (1) can be regarded as a major source of H₂, formation of Ni-rich metal alloys at advanced stages of the alteration would retard the process of metal oxidation.

Formation of fayalitic olivine at the expense of Fe⁰ and SiO₂(aq) and formation of tochilinite through alteration of FeS and Fe⁰ provide two more plausible sources of H₂. However these reactions produce only 1 mole of H₂ per 1 mole of Fe⁰ reacted, less than reaction (1) does. Aqueous conversion of enstatite to ferrous olivine [7] is a less important source of H₂.

Once Fe⁰ is consumed, the amount of H₂ could be stabilized by achieving equilibrium among magnetite and fayalite: $\text{Fe}_3\text{O}_4 + \text{SiO}_2(\text{aq}) + \text{H}_2 \leftrightarrow 1.5\text{Fe}_2\text{SiO}_4 + \text{H}_2\text{O}(\text{l})$ (2). For example, formation of H₂ in hot zones could be compensated by H₂ consumption through the $\text{Fe}_3\text{O}_4 \rightarrow \text{Fe}_2\text{SiO}_4$ conversion in colder zones, consistent with observations [e.g., 3]. Equilibrium (2) can be achieved only at relatively low values of f_{H_2} , which may imply escape of H₂ produced by reactions with Fe⁰. Fayalite-magnetite assemblages observed in ordinary chondrites and in CV3 carbonaceous chondrites [e.g., 3] indicate the possibility of such equilibration, at least at the ηm -mm scale. Note that Fe₃O₄-FeS equilibration could also participate in the buffering of H₂.

Oxidation of Fe^(II)-silicates (e.g., the reverse of reaction 2) may not be the *primary* source of H₂, because Fe-rich silicates form in many cases through aqueous alteration on parent bodies, consistent with mineral substitution patterns, oxygen isotope data, and isotopic dating.

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