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Maghemite as an astrobiology indicator on the Martian surface: Reduction of iron oxides by early organic compounds to generate magnetic phases

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The magnetic iron oxide mineral maghemite could be a useful indicator for astrobiology on Mars. The magnetic experiments on the Viking and Pathfinder missions are best explained by the presence of a few wt.% Fe_2O_3 as tiny maghemite grains imbedded in the 2-3 μm dust/soil particles (Hargraves et al., 1977; Madsen et al., 1999). However, a unique formation mechanism for this maghemite on Mars has not been determined. Possibilities include high-temperature reduction of hematite followed by oxidation of magnetite, dehydroxylation of lepidocrocite, oxidation of Fe(II) in solution, and the reduction/oxidation (redox) of ferric oxide phases, such as ferrihydrite (Cornell and Schwertmann, 1996).

We have performed low-temperature redox reactions on selected hydrated ferric oxide minerals (Bishop et al., 2006). Our lab experiments are designed to test plausible reactions of hydrated iron oxide minerals on Mars in an effort to identify the current iron oxide bearing minerals present there, as well as to understand the character of minerals present earlier and the alteration history of the surface. Our work indicates that these reactions are highly sensitive to the redox environment. Experiments on ferrihydrite and goethite showed that heating these minerals in a dry oxidizing environment produces fine-grained hematite. Heating ferrihydrite in a reducing environment produces fine-grained magnetite. Under Mars-like oxidation levels this magnetite then oxidizes to maghemite. These reactions are dependent on the presence of water and organic material that can act as a reductant. We are using reflectance and Mössbauer spectroscopies to characterize the reaction products and TEM to analyze the sample texture.

Our preliminary results indicate that magnetite and maghemite could be formed in the soil on Mars from nanophase ferric oxide species such as ferrihydrite if organics were present on early Mars. In order for this reaction to take place, however, a reductant is needed and no conclusive evidence for organic species (reductant) was found by the Viking biology experiments (Klein, 1978). One explanation could be that the organics in the upper levels of the surface reacted with ferrihydrite to form maghemite and are no longer present there. Maghemite is formed naturally on Earth from ferrihydrite and goethite in forest fires where organic C is the reductant (Campbell et al., 1997). Our experiments and others (Campbell et al., 1997), indicate that this reaction takes place in the 200 to 400˚C range in a matter of minutes, which could be achieved on Mars through impact events, hydrothermal activity or volcanic venting. Given geologic time scales, the reduction of nanophase ferric oxides should have been possible on Mars at near freezing temperatures, assuming the presence of organic reductants, periodic thermal activity, and a favorable redox environment.

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