

THERMALLY TRANSFORMED NONTRONITE AS A COMPONENT OF THE RED DUST LAYER ON MARS. P. Gavin¹, V. Chevrier¹, P. Rochette². ¹W.M. Keck Laboratory for Space Simulations, Arkansas Center for Space and Planetary Sciences, 202 Old Museum Building, University of Arkansas, Fayetteville, AR 72701. ²CEREGE, Europole Mediterranee de l'Arbois, Aix-en-Provence, France. <vchevrie@uark.edu>.

Introduction: A very thin layer of red dust covers the surface of Mars; this dust has specific properties in terms of mineralogy and chemical properties. But its precise origin remains controversial. Alternatively, phyllosilicate outcrops have been recently identified on Mars by the Mars Express OMEGA visible-near (VIS-NIR) infrared spectrometer [1,2]. These observations represent the first clear identification of clay outcrops on Mars. These outcrops, localized exclusively on the Noachian south crust, contain mainly smectites: Al (montmorillonite), Mg (saponite) and Fe³⁺ (nontronite) [1].

Several works, conducted after the Viking mission, have shown that impacted and heated nontronite could contribute to the mineralogical properties of the martian regolith [3,4]. Since these outcrops have been found on the oldest, intensively craterized crust, they may have been metamorphized and incorporated into the regolith.

Previous impact experiments on nontronite induced a spectral reddening of the phase, resulting from the amorphisation and crystallographic change of the Fe³⁺ ion [3]. In addition, heating may also induce the formation of exotic secondary magnetic phases [5].

Therefore, in this study we intend to reinvestigate the thermal and impact pressure effect on nontronite as a source of Fe³⁺ phases on Mars. In previous studies, nontronite was always impacted in air that contains a lot of oxygen O₂, a strong oxidant. However, early martian surface was rather rich in CO₂. Therefore we performed experiments in a CO₂ atmosphere. This abstract summarizes our preliminary results on this series of experiments.

Atmosphere	T (°C)	Time (h)	Munsell Color	Mass Loss (g)
Air	1000	4	10R 3/3	0.21
Air	750	6	5YR 4/6	0.21
Air	500	24	7.5YR 3/4	0.22
CO ₂	1000	4	5YR 3/4	0.31
CO ₂	900	6	10YR 3/2	0.25
CO ₂	750	6	5YR 3/4	0.20
CO ₂	500	20	7.5YR 4/4	0.20

Table 1. Experimental conditions for heating nontronite.

Experimental protocol: one-gram samples were placed in the middle of a ceramic heating tube, where heating is optimal. The oven was then turned on to the desired temperature. Experiments of several different

durations and temperatures were performed. Experiments were performed in air or under a CO₂ flow, isolating the inside of the furnace from the outside environment. When the sample and tube had cooled, the sample was scraped out into a metal weighing dish, weighed, and this weight was recorded. Pictures of the treated sample next to a non-treated sample were taken to show the color change, which was precisely characterized using a Munsell soil color chart. The samples were then analyzed by infrared reflectance, X-ray diffraction, and ESEM to analyze the samples. These mineralogical analyses were completed by magnetic properties analyses to characterize the iron mineralogy.

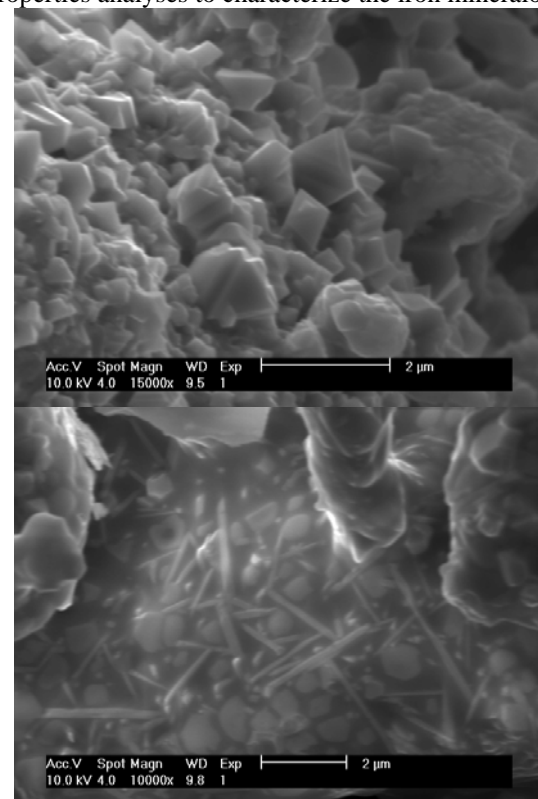


Figure 1: ESEM photographs of secondary products resulting from high temperature heating of nontronite. *Top:* cristobalite crystals formed at 1000°C in the CO₂ atmosphere. *Bottom:* needle crystals of sillimanite formed at 1000°C in the air atmosphere.

Results: nontronite is completely destroyed at temperatures as low as 350°C, with an average mass loss of 22 ± 4 wt% (probably linked to water). The color of all nontronites changes during heating from light green to dark reddish brown. Almost every step in temperature and atmosphere induces different color, but gener-

ally products in CO₂ are more brown while they become more red in air (Table 1). Low temperature products are lighter and high temperature heating produces dark products. This suggests that different products are formed according to the conditions.

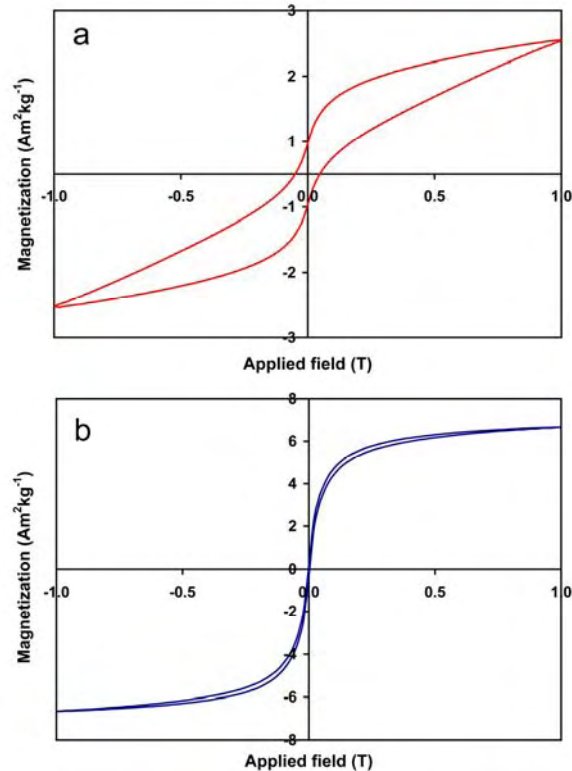


Figure 3: Hysteresis cycles of heated nontronite: (a) Air at $T = 750^{\circ}\text{C}$ for 24 h. (b) CO₂ atmosphere at $T = 900^{\circ}\text{C}$ for 6 h. Both signals probably correspond to 2 different phases.

XRD shows complex mixtures of phases, hard to decipher. Most XRD diffractograms show broad peaks and large background typical of poorly crystalline and nanophase materials. Only high temperature (1000°C) experiments produced well formed crystals, because of higher diffusion of ions, and probably melting and recrystallization. There are no strong differences in the nature of the secondary products between air and CO₂. Until now we mainly identified cristobalite (Fig. 1) at temperature of 750°C or higher. At lower temperatures, quartz is formed. Aluminum concentrates into sillimanite at 1000°C (Fig. 1) and in anorthite at lower temperatures. The only iron phase identified was hematite in XRD and in ESEM. ESEM observations showed that only at very high temperatures, crystals could be identified. However, several XRD features remain unexplained, suggesting the presence of other phases.

Preliminary results of magnetic properties (hysteresis and thermomagnetic curves) show that the magnetic mineralogy is dominated by a mixture of 2

strongly magnetic phases in variable relative concentrations depending on the atmosphere and the temperature. However, both signals are always present in both atmospheres. One of the signals correspond to a phase with a high coercivity (Fig. 3a, H_{CR} of about 500 mT), which saturates around 5 T. We could not determine the precise saturation magnetization of this phase since it is intimately mixed with other products. This phase seems to have a low Curie temperature, around 200°C and probably corresponds to the phase previously identified by [5]. The second phase has a hysteresis signal very close in shape to spinel (Fig. 3b). However, no spinel-type Curie temperature has been identified. The magnetic susceptibility rather decreases linearly in the range 200 – 500°C. Hysteresis properties of the first phase (high coercivity, saturation at high field of about 5 T) seems to indicate hematite, while the very low coercivity and low saturation field of the second is rather in favor of a spinel phase. However, the very unusual thermomagnetic curves, and Curie temperatures of these phases suggest substituted hematite and magnetite, eventually with Si or Al. These “exotic” phases could describe the unattributed peaks in the X-ray diffractograms.

Conclusions: heated nontronite reproduces a lot of known properties of the martian red dust, especially the red color, the presence of hematite probably as a nanophase [6], and the highly magnetic phases [7]. In addition, other accessory phases are produced during heating, such as cristobalite and sillimanite. Potential future detection of these phases could be a good indicator for the presence of heated / impacted nontronite in the martian red dust. Future work includes:

- TEM studies of the particles, and especially the magnetic ones, to determine their composition and the presence of potential substitutions.
- Reflectance measurements in the NIR (OMEGA) and MIR (TES) to compare with observations. This work has been started but the spectral features have not been still identified.
- Impact experiments using a light gas gun to test the effect of shock pressure and compare with heating.
- Similar experiments on other smectites like montmorillonite or saponite.

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References: [1] Poulet F. et al. (2005) *Nature* 481, 623-627. [2] Bibring J.-P. et al. (2005) *Science* 307, 1576-1581. [3] Weldon R. J. et al. (1982) *J. Geophys. Res.* 97, 10102-10114. [4] Boslough M. B. et al. (1986) *J. Geophys. Res.* 91, E207-E214. [5] Moskowitz B. M., R. B. Hargraves (1984) *Science* 225, 1152-1154. [6] Morris R. V. et al. (1989) *J. Geophys. Res.* 94, 2760-2778. [7] Goetz W. et al. (2005) *Nature* 436, 62-65.