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Recreating Intercalated Clays of Chondritic Meteorites

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Introduction

In order to better understand the reactions that form intercalated clays in carbonaceous chondritic (CC) meteorites, we baked a suite of minerals at a temperature of 200°C in sealed Parr bomb containers for a period of three months.

Reflectance spectra of CC meteorites differ from those of mixtures of the end members made physically. They differ in that the CC spectra are darker and show extremely subdued absorption bands of the phyllosilicates (clays) that they contain relative to the mechanical mixtures. This is likely due to the fact that the clays in CCs contain darkening agents, such as organics, magnetite, iron sulfides in intimate association with the clays (i.e., between individual phyllosilicate sheets) that a mechanical mixture just can't reproduce.

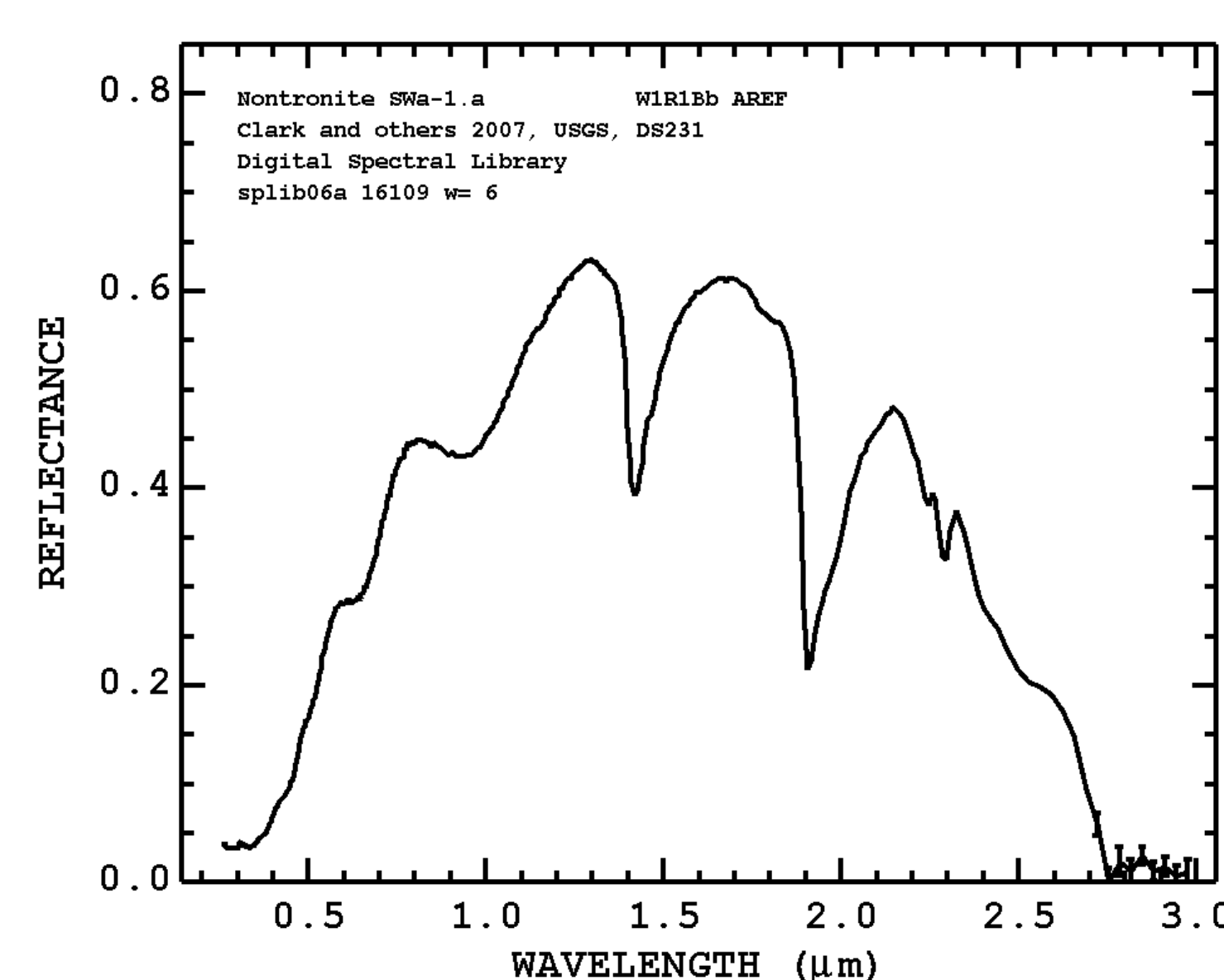
Materials can be introduced between the layers of swelling/expandable clays via cation exchange (intercalation).

The suite contained six combinations of nontronite plus fine-grained metal, organics, or sulfur, with or without water. These combinations were selected based on the range of materials we expect to be available to react on chondritic bodies within our solar system.

Methods

- Nontronite collected from the SWa-1 site in Grant County Washington in the summer of 2016 was used as the base of each mixture.
- This nontronite is a USGS standard, its chemical composition and reflectance spectrum are displayed below (Fig. 1).
- The collected nontronite samples were powdered, and about 0.8 grams (range of 0.8000 to 0.8045 grams) was included in each mixture.
- Sulfur, magnetite, or lampblack (carbon black) were also powdered, and about 0.2 grams (range of 0.1998 to 0.2004 grams) were mixed with each portion of nontronite at an 80/20 ratio of nontronite to the other material.
- Once thoroughly mixed, each of the six powder combinations was analyzed with an ASD spectrometer before being placed into a Parr bomb container. A LabSpec 4 Hi Res ASD was used to take measurements over the 0.350 to 2.500 μm range of these powdered samples. The ASD was allowed to run for over an hour before data collection began to allow the detectors and light sources to stabilize. Before data collection of the sample mixtures began, a Spectralon 99% diffuse reflectance standard was measured to optimize instrument performance.
- Two of each nontronite + other material combinations were made, one of which included about 1 gram of deionized water added to it once in the Parr bomb. The Parr bombs were then sealed and placed in an oven at 200°C for three months. After this three month period, the samples were removed from the oven and re-measured with the ASD spectrometer using the same method described above.
- The ASD spectrometer used has a spectral resolution between 3 and 6 nm. For each sample, 200 spectra of the dark current, standard, and sample were acquired and averaged in order to provide a high signal to noise.

Figure 1. (Right)
Reflectance spectrum of SWa-1 nontronite [3]
($\text{Na}_{0.33}\text{Fe}^{3+}_2(\text{Si},\text{Al})_4\text{O}_{10}\cdot n\text{H}_2\text{O}$)



Results

After heating, all of the dry heated samples appear to be very fine grained. The wet-heated samples appear to have formed larger aggregates of smaller particles.

The pre-heated magnetite + nontronite mixtures (Fig. 2) exhibit the strong NIR blue slope of magnetite, peaking near 750 nm. After both dry- and wet-heating, the magnetite appears to have formed hematite, with no spectrally significant differences between the two post heating spectra.

The sulfur + nontronite mixtures (Fig. 3) have formed at least some Fe-sulfate phases, as evidenced by the characteristic absorption band near 430 nm that now appears. Both of these heated samples are bluesloped in the visible spectral region, perhaps due to formation of Fe sulfides. XRD analysis will give more insight into the mineralogical makeup of these samples.

The post-heating lampblack + nontronite spectra (Fig. 4) appear very different. The dry-heated mixture became very brown, indicative of the formation of brown carbon. This is consistent with the results of Parr bomb dry-heating of siderite and humboldtine, which were found to form a wide variety of intermediate and reduced organic compounds [1]. The wet heated sample spectrum appears much like a lampblack spectrum, with an additional peak in reflectance near 610 nm. The darkening of this sample is likely due to the nanophase lampblack particles fully enveloping the nontronite grains, inhibiting any penetration of light, and therefore the reflectance properties of those grains.

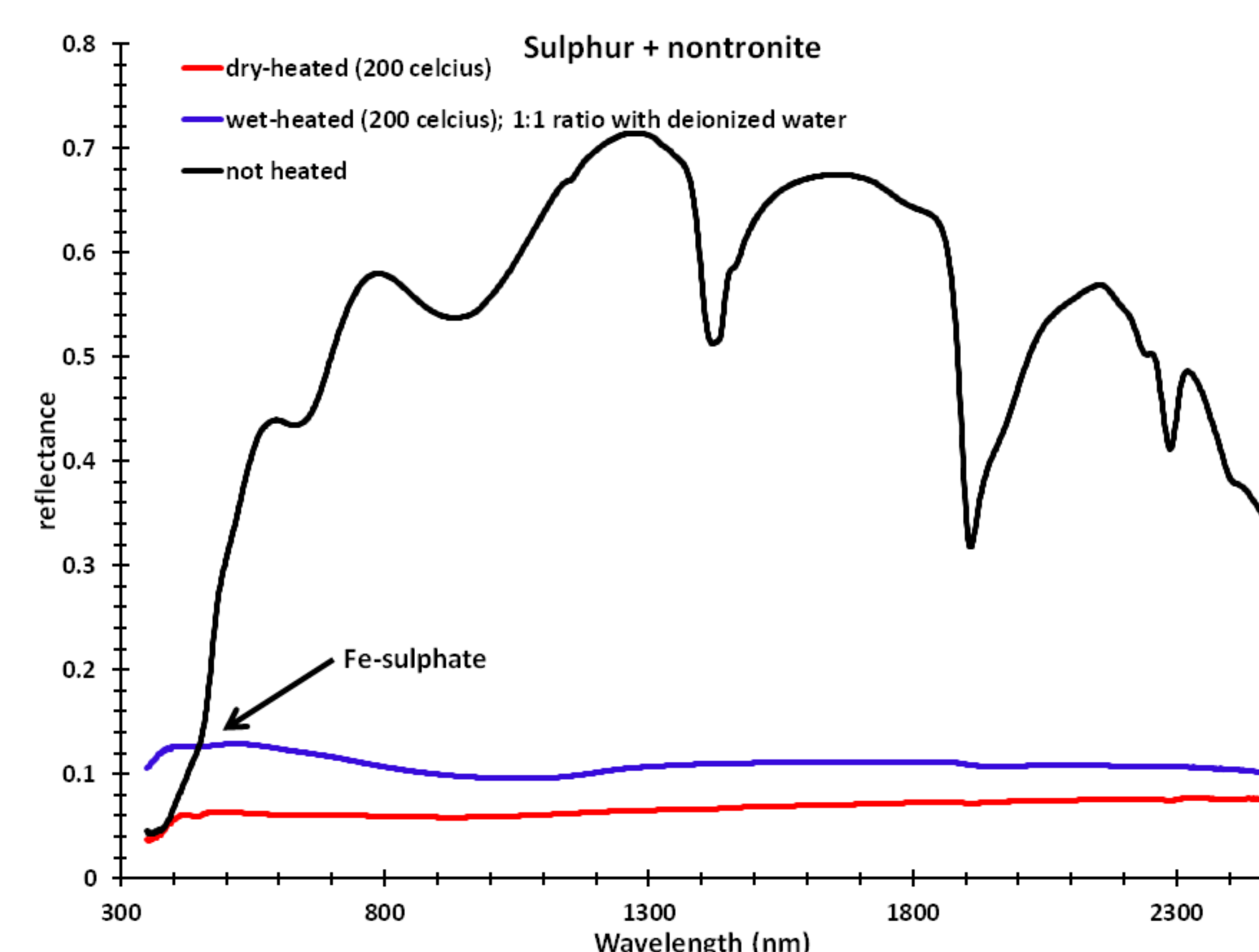


Fig. 3. Reflectance spectra of sulfur-nontronite mixtures.

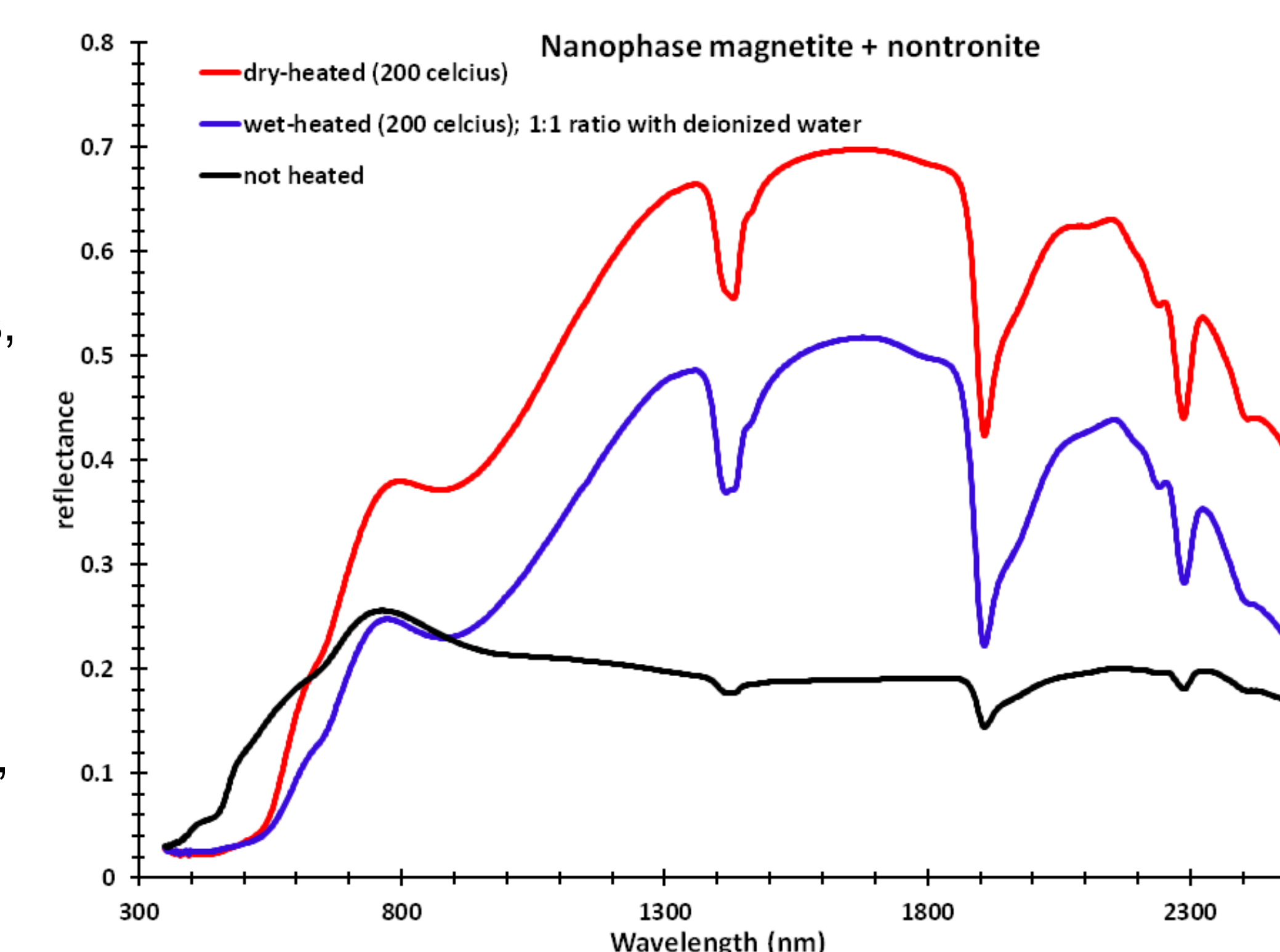


Fig. 2. Reflectance spectra of magnetite-nontronite mixtures.

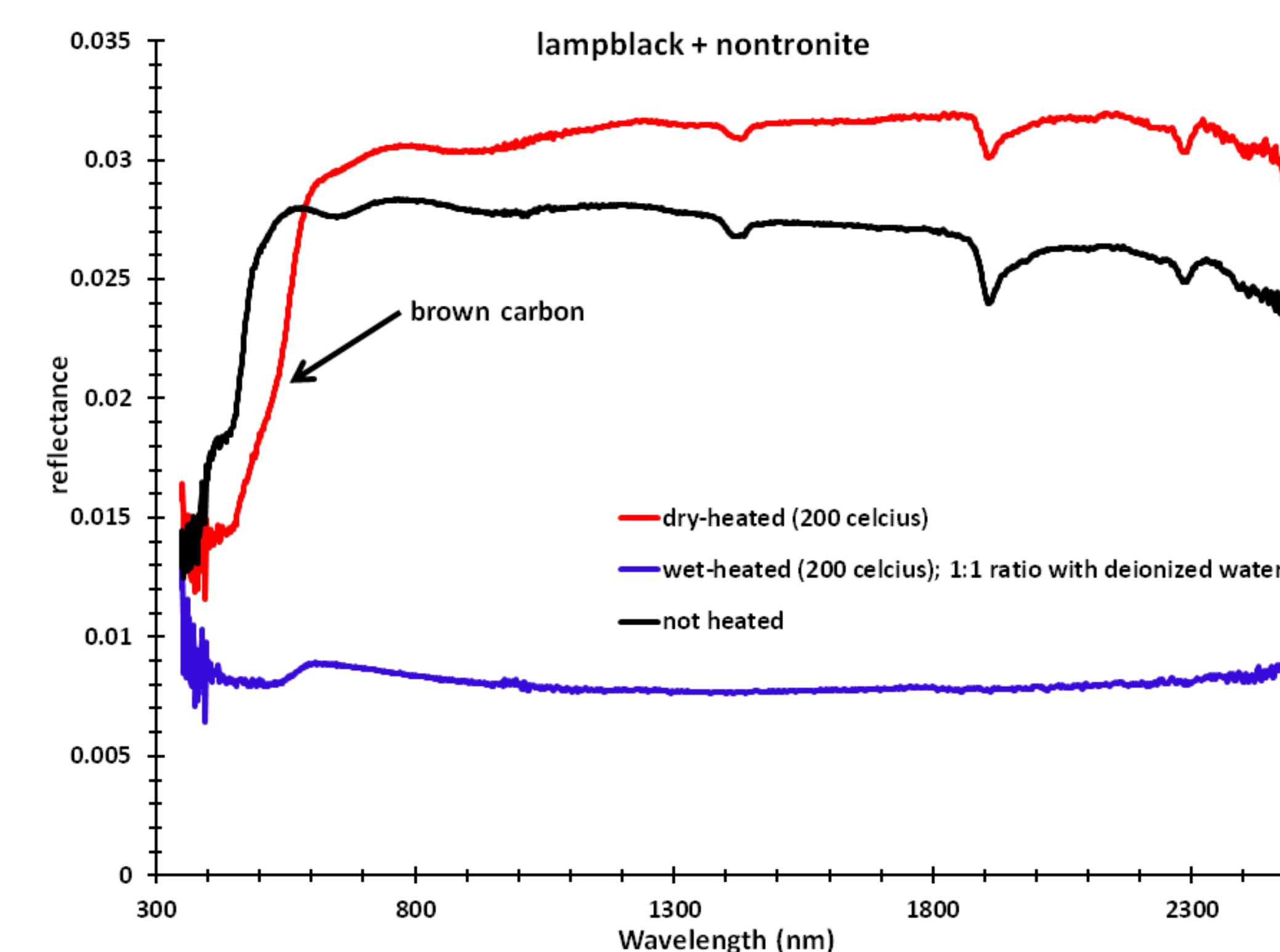


Fig. 4. Reflectance spectra of lampblack-nontronite mixtures

Conclusions

Various differences between wet- and dry-heated mineral mixtures have been observed. In general, it appears that magnetite formed hematite, sulfur formed at least some Fe-sulfates, and the carbon mixtures formed both brown carbon and reduced spectral contributions from the nontronite.

One of the interesting preliminary results from this study is that it appears that dry heating of magnetite-bearing mixtures that include phyllosilicates can result in the production of hematite-like phases. This is at odds with the observation of magnetite in carbonaceous chondrites, such as C11 that have been pervasively aqueously altered.

These results suggest that the presence of water during heating of carbonaceous chondrite precursors can have a strong influence on the spectral properties of the resulting products and that evidence of dry or wet heating may be derivable from such spectra. Ongoing detailed analysis of the samples will provide further insights into the mechanisms that accompany wet and dry heating.

References

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2. Connolly H. C. Jr. (2005) *Science* 307(5706), 75-76.
3. R. N. Clark, G. A. Swayze, R. Wise, K. E. Livo, T. M. Hoefen, R. F. Kokaly, and S. J. Sutley, 2007, USGS Digital Spectral Library sp1106a U.S. Geological Survey, Data Series 231

Future Work

Further experiments are planned at HOSERLab to more thoroughly investigate the effects of the atmosphere in contact with the samples in the Parr bombs.

There are also plans to run similar experiments with more complicated mixtures of more than two components. Fe and Mg rich silicates such as Olivine are also common on CC meteorites [2], and would be good additions to future experiments.

Acknowledgements

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