**AMMONIATION OF PHYLLOSILICATES, CARBONACEOUS CHONDRITE METEORITES, AND IMPLICATIONS FOR THE NATURE OF AMMONIATED MATERIALS ON CERES.** B.L. Ehlmann[1,2], R. Hodyss[2], E. Ammannito[3], G.R. Rossman[1], M.C. De Sanctis[4], C.A. Raymond[2]. [1]Division of Geological and Planetary Science, California Institute of Technology, 1200 E California Blvd, MC 150-21. Pasadena, CA, 91125. (ehlmann@caltech.edu), [2]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr, Pasadena, CA 91109. [3]Dept. of Earth Planetary and Space Sciences, University of California, Los Angeles, California, [4]Istituto di Astrofisica e Planetologia Spaziali, Istituto Nazionale di Astrofisica, Rome, Italy

**Introduction:** Ammonciated- and phyllosilicate-bearing materials were discovered on Ceres and globally mapped with the VIR imaging spectrometer on the Dawn mission [1-3]. Key Ceres infrared spectral features are located at ~3.05 µm, indicating $NH_4$-bearing materials, and 2.72 µm, indicating Mg-OH-bearing materials. Their co-occurrence everywhere on the surface [3] makes it likely, but not certain, that Mg phyllosilicates are the carrier of the ammonium. Readily available spectral libraries have ammoniated, Al-phyllosilicates, which have been used in radiative transfer unmixing models to estimate the composition of the Ceres surfaces [2]. Yet, more suitable may be Fe- or Mg-phyllosilicates, which are more likely from meteoritic materials. Here, we obtain, purify, and ammoniate a variety of Ceres-relevant analog materials, including both phyllosilicates and meteorites. We then evaluate (i) which phases ammoniate; (ii) which ammoniated phases exhibit absorptions with similar positions, widths, and shapes to those observed for Ceres; and (iii) if/how the $NH_4$-related absorptions change at different temperatures under vacuum [detailed further in 4]. The overarching goals are to refine the identification of the ammoniated species on Ceres and develop a spectral library suitable for accurate, quantitative radiative transfer models that estimate Ceres' composition.

**Methods:** Fe/Mg phyllosilicates from the smectite, chlorite, and serpentine families were obtained, powdered, checked for purity with FTIR and/or XRD, purified by settling to diminish the non-phyllosilicate fraction or treated with acetic acid to remove associated carbonates (if needed), and sieved to <150 µm. Similarly, powdered fractions from CM and CI meteorites with spectral properties similar to some asteroids [5] were obtained. Samples listed in Table 1 were measured with a iS50 FTIR instrument in biconical diffuse reflectance mode over 2-25 µm at room temperature. Samples were then ammoniated at room temperature with ammonium acetate followed by acquisition of spectra, also at room temperature, to evaluate whether ammoniation occurred. Samples showing signs of ammoniation were then measured while being cooled from 300 K to 90 K, under vacuum (base pressure ~3x10$^{-5}$ Torr) using a Nicolet 6700 FTIR fitted with a diffuse reflection accessory (Pike Technologies DiffusIR) at a 30° incidence.

Table 1. Materials ammoniated in this study

| | | | |
|---|---|---|---|
| Phyllosilicates | Fe-smectite | Nontronite | NAu-1 |
| | Fe-smectite | Nontronite | NAu-2 |
| | Fe-serpentine | Cronstedtite | CIT-17639 |
| | Fe-serpentine | Cronstedtite | H-2320 |
| | Mg-smectite | Saponite | IMV |
| | Mg-smectite | Saponite | Sap_Gr |
| | Mg-smectite | Saponite | Sap_Baja |
| | Mg,Li-smectite | Hectorite | SHCa-1 |
| | Mg,Li-smectite | Hectorite | SynH-1 |
| | Mg-Serpentine | | OM12_003 |
| | Mg-Serpentine | | OM12_016 |
| | Mg-chlorite | Ripidolite | CCa-2 |
| | Al-smectite | Montmorillonite | SAz-2 |
| | Al-smectite | Montmorillonite | SWy-3 |
| Meteorites | Murchison (CM2) | | |
| | Murray (CM2) | | |
| | Cold Bokkeveld (CM2) | | |
| | Orgueil (CI1) | | |
| | Mighei (CM2) | | |
| | Tagish Lake | | |

**Results:** Smectite minerals readily ammoniated at room temperature. Al smectite spectra matched those in existing databases [e.g., 6], while Mg smectite materials showed absorptions between 3.03-3.06 µm due to $NH_4$ and at 2.72-2.78 µm due to Mg-OH (Fig. 1). The latter were sometimes in a doublet. These spectral characteristics of the ammoniated Mg smectites persist in vacuum and down to 90 K (Fig. 2). Fe smectite materials

Figure 1. SWIR spectra of two Mg smectites before (black) and after (orange) ammoniation

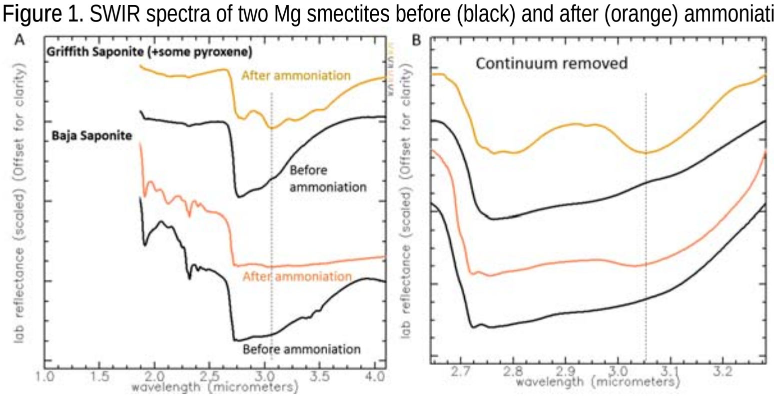
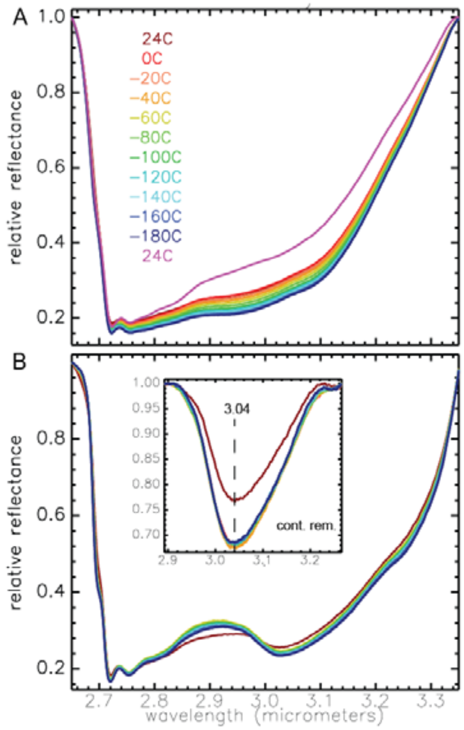


Figure 2. SWIR spectra of the Baja Rosarita saponite (an Mg smectite), (a) not ammoniated and (b) ammoniated and acquired under vacuum temperatures from 297 K to 93 K.




showed signs of ammoniation, but also the formation of a dark precipitate, perhaps due to reaction of the iron to form Fe oxides. Future work will include XRD of the ammoniated Fe smectites. As anticipated, serpentines and chlorites did not ammoniate. These phyllosilicates lack the interlayer of smectites for hosting of species with positive charge. No evidence for loosely bound (e.g., adsorbed) $NH_4$ was seen in their spectra (Fig 3).

Meteorite spectra from Murray and Mighei did not show appreciable change upon ammoniation. The Cold Bokkeveld sample did develop an absorption between 3.0-3.1 μm, which might be attributed to ammoniation, although the shape and position of the band are not a good match for the shape and position of the ~3.05 μm absorption band in VIR data from Ceres (Fig 4). Sample hydration may instead be responsible. Future work will examine the effects of treatment with water alone for comparison to determine if the effect is one of (re-?)hydration, rather than ammoniation. Future work will also examine the more smectite-rich Tagish Lake and additional data from Orguiel.

Figure 3. SWIR spectra of two Mg serpentines before (black) and after (orange) ammoniation

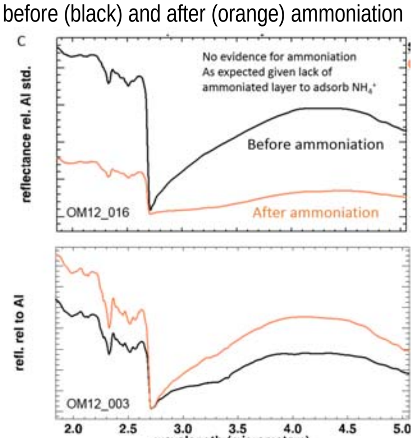
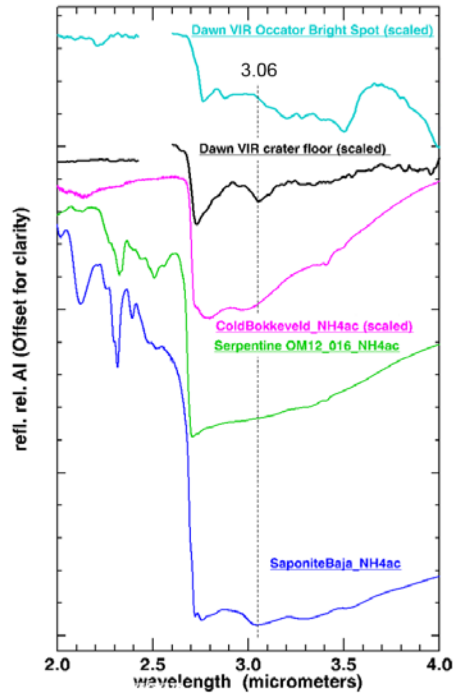



Figure 4. SWIR spectra of Ceres [7] compared to the Cold Bokkeveld meteorite, serpentine, and ammoniated Mg smectite




**Key Findings Related to Ceres & Future Work:** Smectite family minerals readily ammoniate under the conditions whereas serpentine and chlorite family minerals do not. This is expected, given that smectites can readily exchange interlayer cations for $NH_4$ in solution whereas other phyllosilicates lack this high cation exchange capacity. Materials from some carbonaceous chondrites may ammoniate while most do not, possibly related to the proportion of explandable clay minerals like smectites vs. serpentines in the sample. Smectite-rich meteorite samples will be treated to examine for evidence of ammonation. Interestingly, so far, only the Mg smectites produce an ammoniation feature that robustly matches the Dawn VIR and Dawn telescopic data (Fig. 4), robust against changing temperature (Fig. 2). However, the deepest metal-OH absorption feature of the Mg-smectites occurs at a different absorption position (2.76 μm) than observed on Ceres (2.72 μm). This implies there may be two distinct phases responsible for the Ceres spectrum. Speculatively, both ammoniated Mg-smectites and Mg-serpentines may be present, futher reinforcing the similarity with highly altered carbonaceous chondrites, which possess both of these phases.

**References:** [1] King et al., 1992, *Science* [2] DeSanctis et al., 2015, *Nature* [3] Ammannito et al., 2016, *Science* [4] Ehlmann et al., 2017, in prep for submission to *Met. & Plan. Sci.*, Ceres special issue [5] Takir et al., 2013, *Met. & Plan. Sci.* [6] NASA Keck RELAB database, Brown University [7] DeSanctis et al., 2016, *Nature*