**Introduction:** Smectites are the most abundant class of phyllosilicates on Mars. Fe-Mg bearing interstratified smectite-chlorite has been identified as the most common phyllosilicate mineral assemblage, closely followed by an iron-rich smectite similar to nontronite [1]. Nontronite has been specifically identified in Nili Fossae [2] and Mawrth Vallis [3]. Both of these regions have been heavily bombarded by impacts and phyllosilicate occurrences in these regions frequently correspond with the evidence of these impacts. Bibring, et al [4], noted that in Syrtis Major and Nili Fossae, phyllosilicate-rich rocks are detected both within ancient craters and recently excavated ancient terrains. This supports the hypothesis that phyllosilicates on Mars are old and impact processes may have altered their spectral properties. Recent work by Che and Glotch [5] further supports this hypothesis. They find that a unique spectral feature associated with the nontronite-rich deposits around Nili Fossae identified by OMEGA [6] is consistent with nontronite thermally-altered at 400°C.

Previous work on the spectral effects of impacts and related processes on phyllosilicates showed that thermal alteration causes spectral change related to dehydration and/or dehydroxylation. Most phyllosilicates undergo these changes between 100-500 °C [7-14]. Thermal alteration has also been shown to change the color and magnetization of nontronite samples [15]. In contrast, impacts cause spectral change by increasing structural disorder in phyllosilicates, especially in the octahedral sheet, without completely dehydrating or dehydroxylating them [16-18].

Given that both thermal and impact processes cause distinct spectral changes in phyllosilicates and that the effects of each differ from one another, it may be possible to identify impact-altered phyllosilicates on the surfaces of remote planetary bodies by their spectral signatures. Such identifications not only illuminate the geologic history of Mars by confirming that impacts played a role in altering minerals on the planetary surface, but also show that hydrated minerals on the martian surface may have retained their structural H$_2$O after impacts.

**Methods:** We used factor analysis and target transformation (FATT) [19-21] to analyze the CRISM image FRT0013E49_07 of Mawrth Vallis for nontronite spectra similar to those showing evidence of impact-related change. The spectral libraries we used were derived from our own laboratory work exposing phyllosilicates to experimental impacts [17], previous laboratory work investigating spectral change in thermally altered phyllosilicates [13,14], and standard spectral libraries from the USGS and CRISM RELAB databases. We also compared the 1.4/1.9 µm band-depth ratios for identifications from Mawrth Vallis with those from nontronite spectra after experimental impacts and standard spectral libraries.

**Results:** We examined a region of interest in Mawrth Vallis (Figure 1) that contains nontronite spectra similar both to unaltered nontronite and to nontronite after impacts at 3 peak pressures.

![Figure 1. CRISM false-color image FRT0013E49_07, iron-rich minerals (red), olivine source rock (green) and phyllosilicates (blue). The phyllosilicate-rich 130x130 pixel region of interest [285:415, 190:320] that we examined is outlined in red.](image)

FATT identifications of phyllosilicate spectra similar to impact-altered spectra. We used FATT to identify nontronite in Mawrth Vallis, a region of Mars in which Fe/Mg smectites, and nontronite in particular, have previously been identified [3]. We find that FATT robustly matches impact-altered nontronite after impacts of approximately 25 and 30 GPa in the investigated region of interest, and that pre-impact nontronite is matched moderately well, but less well than the impact-altered nontronite spectra (Figure 2).

Comparison of 1.4 and 1.9 µm band depths for impact-altered nontronite, martian nontronite identifications and nontronite spectral library standards. In
comparing the 1.4/1.9 μm band depths for nontronite after experimental impacts, nontronite spectra from Mawrth Vallis, and various standard ferruginous smectite spectra, we find that there is a distinct trend for change in the 1.4/1.9 μm band depth ratio with increasing peak-pressure for nontronite exposed to experimental impacts [17]. Nontronites identified at Mawrth Vallis in our region of interest have band-depth ratios consistent with impacts between 20-25 GPa and 30-35 GPa, consistent with these strong FATT identifications (Figure 3). Band-depth ratios from spectral library spectra are inconsistent and have not been included in Figure 3. However, several samples from common spectral libraries are listed simply as ‘unidentified smectite’ and, since phyllosilicate vibrational bands depend on the cations present, this adds uncertainty to the accuracy of band-depths calculated from the currently available spectral libraries. In contrast, our initial nontronite band-depth ratio was calculated from the pre-impact spectrum of pure, acid-washed NAu-1 nontronite.

Discussion: Phyllosilicate observations from within Mawrth Vallis are consistent with impact-altered nontronite and are spectrally different from pure or thermally altered nontronite. This shows that impact-altered phyllosilicates can be identified independent of thermally altered phyllosilicates [5] and that impact altered phyllosilicates should be considered in the analysis of remote sensing data as an individual phase, which should be taken into account independent of other phases.

Phyllosilicates have been shown by spectral analysis to retain their structural OH and H₂O groups after experimental impacts [17]. Their identification on the martian surface provides direct confirmation of the role that impacts have played in the geologic evolution of planetary bodies. In addition, the retention of structural OH and H₂O by impact-altered phyllosilicates implies that impacts do not induce decomposition in clay minerals [22], but can alter their spectral signatures. These results also show that clays are stable and identifiable using UV-Vis reflectance spectroscopy even after impacts of 30 GPa. Nonetheless, the spectral effects of impacts on phyllosilicates are specific and identifiable, making it important to account for them in the interpretation of planetary remote sensing data.