**THERMALLY ALTERED CLAYS ON MARS.** C. Che[1] and T. D. Glotch[1], [1] Department of Geosciences, Stony Brook University, Stony Brook, NY11794 (cche@ic.sunysb.edu)

**Introduction:** Because most clays detected on Mars are associated with ancient, heavily cratered terrains [1-4], it is likely that at least some of these deposits were repeatedly subjected to shock heating subsequent to their deposition. In this proposed scenario, clays formed prior to the impact events and may have been substantially modified by crater excavation processes. If this was indeed the case, then we would expect thermally altered or impact-shocked [5] clays to be present on the Martian surface today.

Regarding Mars, the post-impact alteration of preexisting clays has been a subject of interest [6-7] and efforts have been made to demonstrate that at least some of the clays in and around Martian craters are consistent with excavated preexisting deposits, rather than new mineralization formed via impact processes [6]. However, the post-impact thermal alteration hypothesis and its potential geologic implications have not received much attention or detailed investigation. We test this hypothesis here by combining our previous laboratory spectral studies with a rigorous remote spectroscopic analysis of Mars. Our results serve as an assessment of the possibility of the presence of dehydrated and dehydroxylated clays on Mars and the potential improvement on our understanding of Martian aqueous history.

**Thermal stability of clays:** We previously obtained laboratory spectra of heated clays and natural zeolites, all identified or tentatively identified on Mars, and have concluded that dehydration via heating leads to changes in the intensities and shapes of major $H_2O$ and $OH^-$ absorption features; the major spectral changes to clay spectra due to thermal alteration are associated with dehydroxylation reactions, collapse of layer structures, and/or recrystallization to new phases [8-9]. At the onset of dehydroxylation, some clays lose all original spectral features in the thermal (TIR) region while displaying the hydration bands in the near IR (NIR) region in the same temperature range (**Figure 1**). The inconsistency between spectral behaviors of thermally altered clays in the TIR and NIR leads us to two hypotheses. First, at least some of the characterized NIR spectral features of clays detected on Mars might be attributable to thermally altered clays, because some of the hydration bands in the NIR region can still be observed at the post-impact temperatures, which have been calculated to be below 700 ℃ in most target areas during impact crater excavation [6, 10]. Secondly, thermal alteration induced by impact processes may be at least partially responsible for the difficulty in detecting clays on Mars using TIR emission spectroscopy.

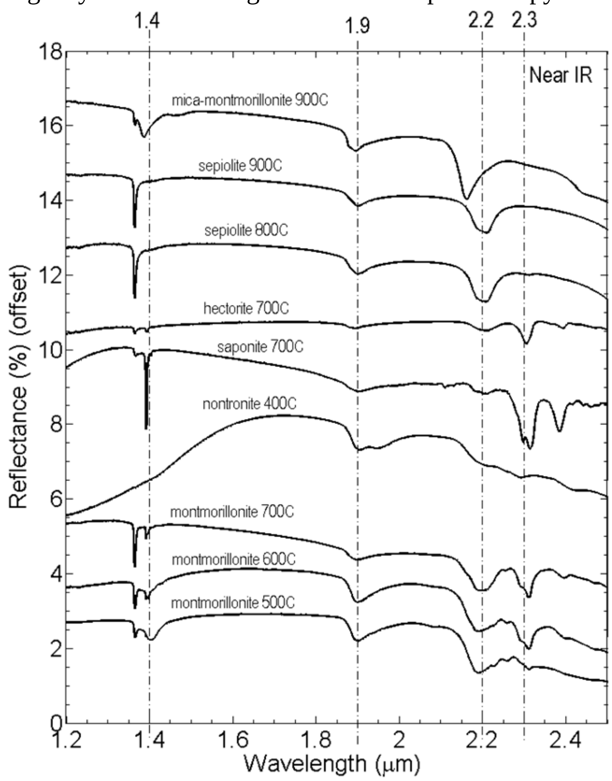


**Figure 1**. Laboratory near-IR spectra of high temperature phases of clays [9].

**Exploring Mars:** *Nontronites in the Nili Fossae Region.* Using a variety of spectroscopic methods, covering NIR to TIR wavelengths, our analysis of remote sensing data suggests that thermally altered (at ~400 ℃) nontronite may be present in Nili Fossae and mixed with unaltered nontronite [11].

*Montmorillonites in the Marwth Vallis Region (**Figure 2**).* Our analysis of VNIR reflectance data from MRO CRISM hyperspectral imager has revealed a unique spectral shape in the Mawrth Vallis region of Mars. This spectral shape has absorption features consistent with the presence of thermally altered Al-rich smectites, specifically 500-700 ℃ heated montmorillonites [12].

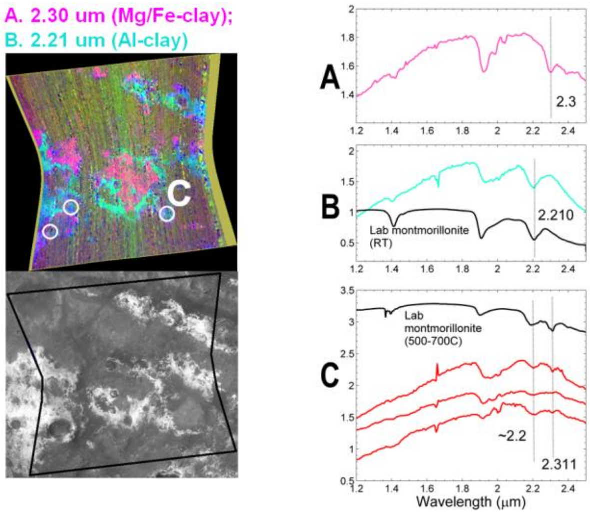


**Figure 2**. CRISM image FRTC467 covering the clay-rich unit in the Mawrth Vallis area, Mars. Lab (black) and CRISM ratio spectra (colors) showing variations in CRISM image FRTC467. Spectra collected from region C displays a combination of 2.2 and 2.311 μm and are consistent with thermally altered montmorillonite.

**Discussion and conclusions:** Remote sensing data of the Nili Fossae and Mawrth Vallis regions [11-12], combined with detailed laboratory studies of the dehydration and dehydroxylation of clays [8-9] strongly suggest that preexisting clays were thermally altered at some point in their history. Theoretically, if impact excavation occurred on ancient Mars, when the scale of groundwater aquifers was likely large enough to support and promote hydrothermal systems, then clays were more likely to be hydrothermally produced after the formation of impact craters [6]. On the other hand, cratering during the Hesperian, with ceased hydrothermal activity and lower water availability would provide favorable conditions for anhydrous thermal alteration (**Figure 3**). Additionally, the generally cold and dry surface conditions available at the time would enable the preservation of dehydrated or dehydroxlyated clays, either at the surface or in the subsurface [13-14].

We suggest that dehydration and dehydroxlyation of clays induced by post-impact thermal alteration was a widespread process during a point in Martian history when the water availability was extremely low or limited to specific areas. Results from this study, together with the potentially limited accessibility to the early hydrothermal systems on ancient Mars, lead us to propose a scenario that preexisting clay sediments were excavated through impact processes, and subsequently modified by high temperatures in the crater centers. Low water availability during cratering processes would make it difficult for these clays to be altered by hydrothermal processes. It is also important to note that the mixing of altered and unaltered clays may be partially responsible for the apparent disconnect between VNIR and TIR observations of clay-bearing surfaces on Mars. The presence of thermally altered clays on the Martian surface also suggests that it is important to consider the effects of post-depositional thermal alteration on Martian sediments as a key component of understanding past Martian habitability and biosignature preservation.

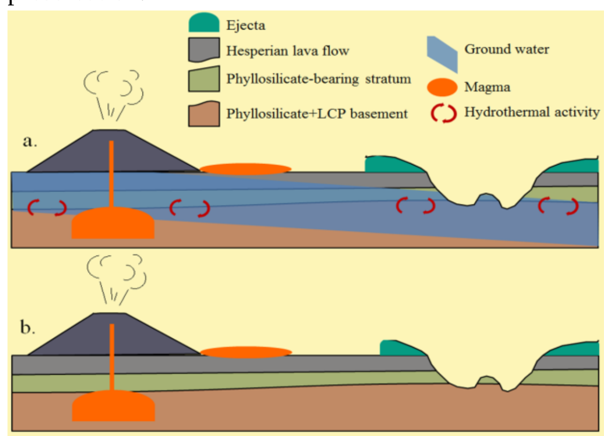


**Figure 3**. Schematic illustration of possible formation mechanisms of thermally altered clays on Mars. **a**, Pre-existing clay layer with pre- and post-impact hydrothermal activity. In a warm and wet subsurface environment, clays are more likely to be hydrothermally formed during the impact processes. **b**, Pre-existing clay layer without hydrothermal activity. A period with ceased hydrothermal activity and declined water availability would provide favorable conditions of thermal alteration. Dehydrated or dehydroxylated clays may be present in the crater ejecta.

**References:** [1] Bibring, J. -P. et al. (2006) *Science* 312, 400--404. [2] Loizeau, D. et al. (2007) *J. Geophys. Res.* 112, E08S08. [3]Poulet, F. et al. (2005) *Nature* 438, 623--627. [4] Mangold, N. et al. (2007) *J. Geophys. Res.* 112, E08S04. [5] Friedlander, L. R. et al. (2014). *J. Geophys. Res.*, in review. [6] Fairén, A. G. et al. (2010) *PNAS* 107, 12095-12100. [7] Ehlmann, B. L. et al. (2011) *Clay. Clay Min.*, 59, 359-377. [8] Che, C. et al. (2011) *J. Geophys. Res.* 116, E05007. [9] Che, C. and Glotch, T. D. (2012) *Icarus*, 218, 585-601. [10] Abramov, O., and D. A. Kring (2005) *J. Geophys. Res.*, 110, E12S09. [11] Che, C. and Glotch, T. D. (2014) *Geophys. Res. Lett.* 41, 321-327. [12] Che, C. and Glotch, T. D. (2014) 45th LPSC, abstract #2112. [13] Morris, R. V. (2010) 41st LPSC, abstract #2156. [14] Morris, R. V. (2011) 42nd LPSC, abstract #2757.