THE TIMING AND DISTRIBUTION OF CLAY AND HYDRATED MINERAL FORMATION IN MARTIAN CENTRAL PEAKS. V. Z. Sun[1] and R. E. Milliken[1], [1]Dept. of Geological Sciences, Brown University, RI, 02912, Vivian_Sun@brown.edu.

Introduction: Current paradigms suggest that Noachian Mars (≥3.7 Ga [1]) was characterized by widespread aqueous alteration and clay mineral formation that largely ceased by the Early Hesperian [2,3]. This has been supported in part by detections of clay minerals in central peaks of impact craters, which are conventionally interpreted to represent ancient, altered Noachian crust excavated from depth [4,5,6]. However, recent studies of Hesperian impact craters (e.g., Holden [7], Toro [8], Ritchey [9]) have determined that some of these clays may have formed *in situ* either during or after the impact event, thus representing more recent Hesperian or Amazonian clay formation. Here we assess the temporal and spatial distribution of clays and other hydrated minerals in central peaks of impact craters. By determining their pre- or post-impact origin and constraining their formation age we can better resolve the timing and duration of aqueous alteration and clay-forming conditions on Mars.

Methods: Craters are selected for study if there exists both CRISM and HiRISE coverage over their central peak regions. Hydrated mineralogy at each crater is characterized from 1-2.6 µm CRISM data [10], with care taken to determine detailed mineralogic boundaries and document subtle variations in mineralogy (e.g., Fe vs. Mg-smectites). Mineralogy is then correlated to stratigraphic and morphologic units as determined from HiRISE images in order to assess pre- or post-impact origin. Identification of fluvial features in broader-scale CTX images provides additional context of water-rock interaction in the crater's history. CRISM data of the crater floor, wall, ejecta, etc. are also analyzed to evaluate hydrated minerals at the central peak in the context of other components of the crater. Approximate ages for craters bearing hydrated minerals are then estimated by crater count dating of the crater's ejecta, which can help to constrain the formation age of any post-impact clays or hydrated minerals.

Results: 534 craters with CRISM and HiRISE coverage over their central peaks have been selected for study (Figure 1). Results thus far from 70 of these craters show that Fe/Mg smectite or mixed-layer chlorite/smectite is the most prevalent hydrated phase, followed by hydrated silica. Other hydrated minerals that have been detected are, in order of prevalence, chlorite, zeolites, and sulfates.

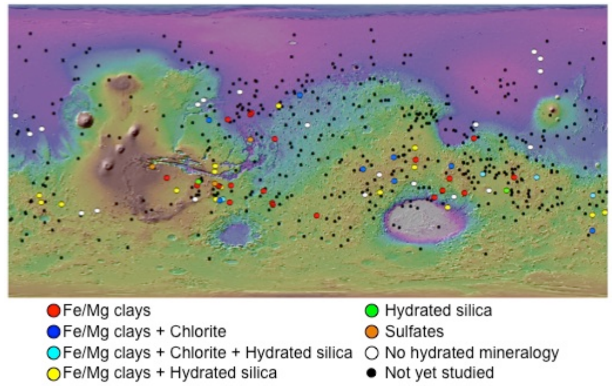

Figure 1. Global survey of 534 central peaks with both CRISM and HiRISE coverage. Colored dots represent craters studied thus far.

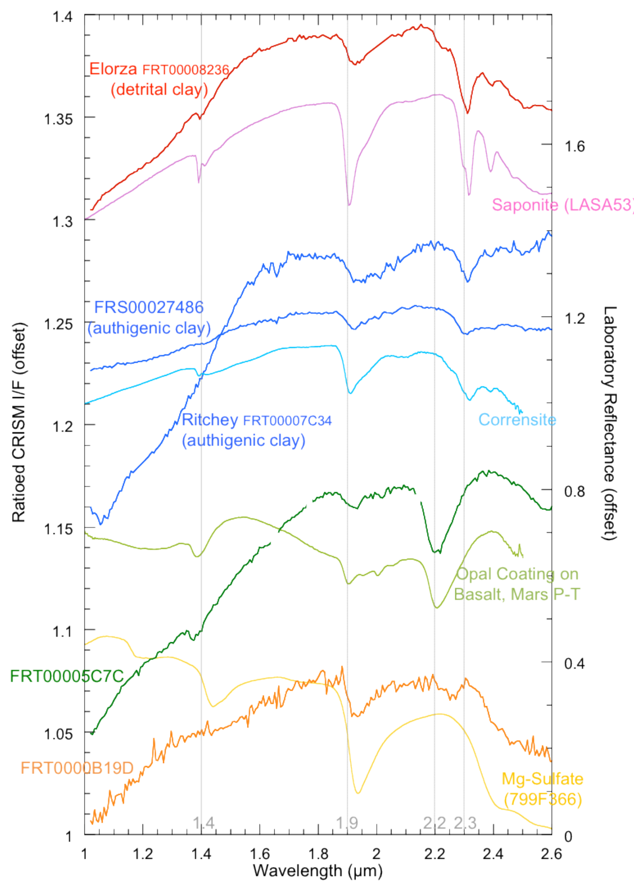

Figure 2. CRISM and library (RELAB) spectra of post-impact clays and hydrated minerals at central peaks.

Fe/Mg Clay Minerals: Clay minerals are primarily of the Fe/Mg variety, although most are consistent with more Mg-rich compositions with absorptions centered at 2.3-2.31 µm (Figure 2). Most of these detections are consistent with smectite or mixed-layer chlorite/smectite (e.g., corrensite), although chlorite is present in some locations. Pre-impact (excavated) clays are observed in bedrock that has clearly been uplifted, whereas post-impact clays are associated with units whose emplacement clearly postdates the impact event. Post-impact clays are further categorized as possible detrital or authigenic deposits. The former are associated with clear sedimentary environments and may exhibit clays in the source region; these cases may represent pre-impact clays that have been redistributed by post-impact processes. An authigenic designation is given when unaltered, uplifted bedrock is superposed by a clay-bearing unit that is commonly observed to have characteristics of impact melt, including brecciation and draping morphology [9]. From initial results, pre-impact clays comprise ~43% of central peak clays, indicating the excavation of ancient, possibly deep-seated Noachian clays. However, putative post-impact clays are nearly as common, constituting ~36% of central peak clays, and are evenly split between possible detrital and authigenic clays. The remaining ~21% of central peak clays have an indeterminate origin and are not associated with well-defined geologic units.

Occurrences of post-impact detrital clays are concentrated in a time period spanning 3.6-4.1 Ga (Figure 3), consistent with the timing of valley network formation near the Noachian/Hesperian boundary [11]. In contrast, the frequency of authigenic clay formation appears consistent from 2.5 to 3.8 Ga, suggesting that the ability of impacts to generate clays may have been constant throughout Martian history, and that clay-forming conditions may have existed locally during the Hesperian and Amazonian.

Hydrated Silica: Hydrated silica is found in ~40% of central peaks with Fe/Mg clays, although two craters bear hydrated silica as the only detectable hydrated phase. These detections occur in either localized unconsolidated deposits or in coherent, light-toned, rough-textured deposits. Ages of craters bearing hydrated silica cluster within a period between 3.4 to 3.5 Ga and are noticeably sparser outside this time interval (Figure 3). If the hydrated silica represents impact glass or the products of impact-related aqueous alteration, then there may have been a change in global conditions from 3.4-3.5 Ga that allowed for the increased formation of hydrated silica relative to other hydrated silicates such as clay minerals. This timing may coincide with the widespread formation of Hesperian-age opaline silica near Valles Marineris [12].

Sulfates: Fe/Mg sulfates are detected and are the sole hydrated mineralogy in three craters, all located at edges of the Valles Marineris system. Sulfate is present in uplifted massive bedrock at one crater and is associated with light-toned sedimentary deposits at the other two craters, consistent with other sulfate-bearing deposits in the Valles Marineris region [13]. These two craters are both dated to 3.6 Ga, within the posited era of sulfate formation [3].

Conclusions and Future Work: Detailed correlation of clays and hydrated mineralogy to geologic units at crater central peaks reveals trends in their distribution and possible formation ages. Although many central peak clays are consistent with excavation of pre-existing clays from the deeper crust (as previously interpreted), a similar proportion of clays are consistent with post-impact emplacement, either as detrital clays in sedimentary deposits or as authigenic clays in putative impact melt. Conditions favorable for authigenic clay formation may have existed as recently as 2.5 Ga during the Early Amazonian. Although near-surface clay formation via weathering may have been most common in the Noachian, the potential for the formation of impact-generated clays may have been constant throughout Martian history. Hydrated silica or glass, possibly produced during impacts, is often associated with Fe/Mg clays and formed predominantly from 3.4-3.5 Ga. Ongoing work will continue to extend this study to all central peaks with CRISM and HiRISE coverage to better constrain the timing, frequency, and distribution of clay and hydrated mineral formation on Mars, providing insight into water-rock interactions through time.

References: [1] Hartmann, W.K. and Neukum, G. (2001) *Space Sci. Rev. 96*, 165-194; [2] Poulet, F. et al. (2005) *Nature, 438,* 623-627; [3] Bibring, J.-P. et al. (2006), *Science 312*, 400-404; [4] Mustard, J. et al. (2008), *Nature 454*, 305-309; [5] Murchie, S.L. et al. (2009), *JGR 114*, E00D07; [6] Carter, J. et al. (2010), *Science 328*, 1682-1686; [7] Tornabene, L.L. et al. (2009), *LPSC 40*, #1766; [8] Marzo, G.A. et al. (2010), *Icarus 208*, 667-683; [9] Sun, V.Z. and Milliken, R.E. (2014), *JGR 119*, doi:10.1002/2013JE004602; [10] Pelkey, S. et al. (2007), *JGR 112*, E08S14; [11] Fassett, C.I. and Head, J.W. (2008), *Icarus 195*, 61-89; [12] Milliken, R.E. et al. (2008), *Geology 36*, 847-850; [13] Roach, L.H. et al. (2009), *JGR 114*, E00D02.

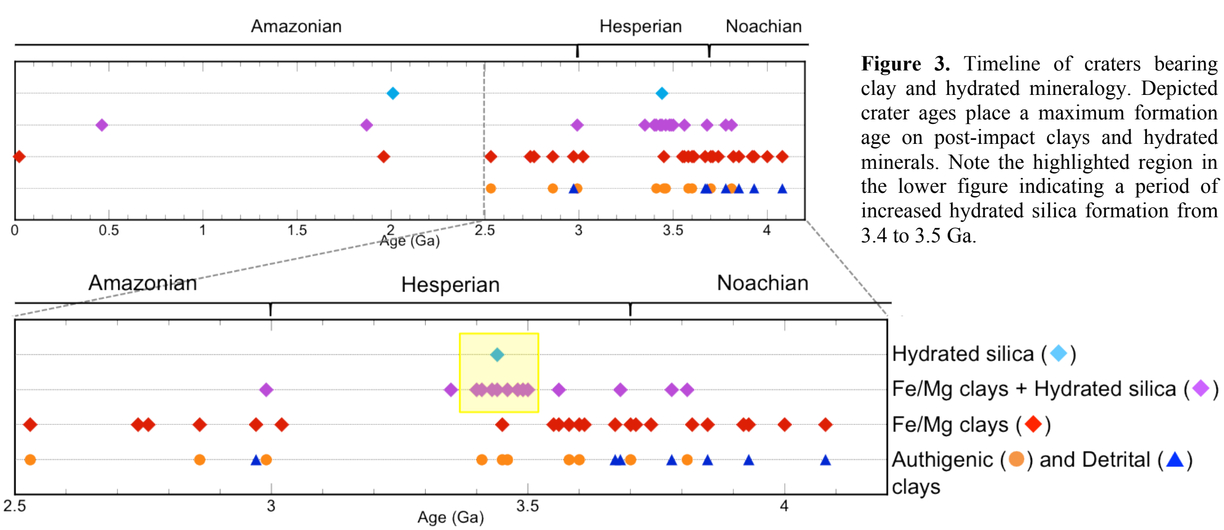

Figure 3. Timeline of craters bearing clay and hydrated mineralogy. Depicted crater ages place a maximum formation age on post-impact clays and hydrated minerals. Note the highlighted region in the lower figure indicating a period of increased hydrated silica formation from 3.4 to 3.5 Ga.