**Introduction:** Robust identification of mineral assemblages is critical when interpreting alteration pathways and past aqueous environments. The Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) near infrared imaging spectrometer has identified dozens of alteration minerals that have deepened our understanding of the aqueous history of Mars [1]. Alteration minerals are frequently important indicators of the geochemical environments in which they formed, providing constraints on fluid composition, temperature, and weathering environments. These mineral phases also frequently occur in either low abundances or in small spatial extents that make them difficult to detect using traditional analyses methods.

Here, we apply machine-learning algorithms to CRISM observations of Gale Crater to investigate strata at the transition between Fe smectite-bearing lacustrine deposits and overlying hydrated sulfate layers in Mt Sharp. This contact zone has been long hypothesized as a record of significant environmental change on Mars [2,3], and is an imminent target for the Mars Science Laboratory Curiosity rover. However, the mineral assemblage of the strata at the transition between the aerially extensive Fe-smectite detections and the hydrated sulfate detections has been difficult to constrain from orbit, due to variable surface exposure and ambiguous spectral absorption features [2,3]. We analyze overlapping CRISM observations to make highly localized mineral detections.

**Methods:** We use a machine-learning based approach for all detections reported in this study. Technical details of our approach are provided in [4]. CRISM I/F TRR3 data between 1.0-2.6µm (248 channels) are corrected for atmospheric interference and photometric effects [5]. Two types of spectral training libraries are used for model training. The first one is constructed with bland patterns using unratioed data. The second one is constructed for mineral phases using ratioed data. The first library is used for training a bland pixel scoring function for column-wise ratioing and the second one is used for training a classifier model that operates on the ratioed data to perform mineral classification. Both the scoring function and the classifier use a two-layer Bayesian Gaussian mixture model (TLGMM). In this two layer architecture the first layer models spectral variability across different patterns whereas the second layer

![Figure 1. Five independent CRISM observations corroborate the detection of a mineral phase with a ~2.21µm absorption feature, likely hydrated silica, within a bright toned outcrop on the western flank of Greenheugh pediment (Red circles). Similar spectral patterns, although less spatially coherent and not apparent in all overlapping CRISM scenes, appear within the orange circle to the east, where the Curiosity rover will continue its ascent of Mt. Sharp.](image)
models spectral variability across different image instances of the same pattern. An ensemble version of the TLGMM is used to compute the likelihood of individual pixels originating from the bland pattern categories, which includes multiple different submodels each with different subsets of channels. Once all pixels in each I/F image are ratioed this way, the ratioed data are used by the mineral classifier, also implemented as an ensemble, for pixel-scale classification. To mitigate false positives we map pixel labels onto the image and identify groups of pixels sharing the same class label and connected to each other with 8-neighborhood connectivity. All connected components with less than three pixels or all detected pixels in the same column are considered less viable and are ignored from further processing. Detections are then manually vetted to ensure accurate identifications, and to place the spectral results into spatial context and cross compare between overlapping CRISM observations.

Results: Spectral retrievals from strata at the transition between the distinct Fe-smectite detections and the hydrated sulfate layers are generally hydrated and have M-OH absorption features that vary in position and strength from 2.2–2.27 μm, consistent with a range of possible alteration minerals including Al-Mg smectite clays, hydrated silica or jarosite [3], and indeed likely contain multiple alteration phases within the mineral assemblage, particularly when considering likely lateral mineralogical variability. Spectral features are not always replicated by all overlapping CRISM observations, due to changes in instrument signal to noise or atmospheric conditions.

We report the detection of a well-localized outcrop with a consistent 1.9μm hydration feature and a broad 2.21μm M-OH absorption that is detected in five independent CRISM observations (Figure 1). The spectral class is associated with an outcrop of light-toned, fractured bedrock (~300x100m) on the western flank of Greenheugh pediment, a morphological feature at the base of Gediz Vallis and a potential significant unconformity in the Mt Sharp stratigraphy. We posit that the spectral features are most consistent with hydrated silica due to the shape of the absorption features, although Al-rich smectite clays (montmorillonites) are also potential matches. This outcrop was mapped in [3] as part of a unit characterized by a steep NIR spectral slope, but has less well resolved M-OH features as a whole.

Similar bright-toned, fractured bedrock can be observed at several intervals along the base of the pediment escarpment, although these outcrops are generally below the spatial resolution of the CRISM instrument. A similar spectral class is also mapped on the eastern side of the pediment at a similar elevation, although the spatial and spectral coherence is less consistent. However, it is possible that similar mineral assemblages may be present in laterally equivalent strata at the transition between major mineralogical units.

Implications: Hydrated silica has been detected by CRISM in limited outcrops on the floor of Gale crater [3,6] and within the greater watershed region [7]. The Curiosity rover has also measured several silica phases in drilled samples, and found many instances of elevated SiO bearing bedrock [8–10], which are interpreted to be both detrital and diagenetic in nature. Authogenic hydrated silica can place limits on fluid chemistry and temperature, as well as constrain repeated instances of alteration events. To date, no CRISM detections of Al-smectite or kaolin clays are reported within Gale Crater and the Mt Sharp stratigraphy, although there are outcrops of Al clays within the watershed region [7]. Although the breadth of the 2.21 spectral absorption is wider than many Al-OH absorptions in the reported outcrop, the addition of Mg or Fe could broaden a typical Al-smectite absorption pattern. Al-clay minerals generally imply open-system alteration environments, either at the surface or in permeable fracture systems, that mobilize soluble Mg and Fe, compared to closed-system alteration that allows Fe and Mg to be incorporated into alteration products.

The presence of hydrated silica (or Al-clays) in outcrops overlying the reported Fe-smectite bearing lacustrine deposits imply a change in the alteration environment in the Mt Sharp stratigraphic succession, and further analysis of both CRISM observations and in-situ exploration will continue to fill in gaps in the record of aqueous alteration in Gale crater.

References: