IS EARLY MARS REALLY MORE ALTERED THAN MODERN MARS? A STATISTICAL ASSESSMENT. C. A. Gibson, M. R. Salvatore, and C. S. Edwards, Department of Astronomy and Planetary Science, Northern Arizona University, Flagstaff, AZ, cag652@nau.edu.

Introduction: The commonly accepted alteration history of Mars hypothesizes that more aqueous alteration occurred on ancient (Noachian) Mars than did on modern (Amazonian) Mars [1]. Visible/Near-infrared (VNIR) spectroscopy has previously been used to identify alteration phases and constrain the timing of their formation [2]. However, no previous study has performed a truly randomized and unbiased statistical investigation of the distribution of alteration phases across the martian surface in order to determine whether reflectance spectroscopy data support this commonly accepted hypothesis.

In this study, we identify a random subset of images acquired by the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) instrument [3] and derive statistical interpretations of the presence, absence, and distribution of identified alteration phases. These data are then used to determine whether there is a statistical relationship between the age of geologic units and the presence of alteration signatures. We also discuss the implications of this work and the biases that may contribute to our investigation and our results.

Methods: The CRISM instrument onboard the Mars Reconnaissance Orbiter generates three-dimensional image cubes that includes hyperspectral VNIR reflectance spectra. Standardized spectral summary parameters are also generated to aid in the rapid interpretation of the data and to identify diagnostic spectral signatures [4,5]. These parameter products are available via the Java Mission-planning and Analysis for Remote Sensing (JMARS) geospatial information system, which was used in all aspects of this investigation.

A subset of 166 targeted CRISM images from the global database was randomly selected from latitudes between ±70° and from landscapes with an albedo less than 20% (as derived from Thermal Emission Spectrometer (TES [6]) data) (**Fig. 1**). Data were then matched to a martian global geologic map [7] to derive the ages associated with each CRISM image.

The following CRISM parameters were used to investigate the nature and distribution of alteration signatures in each image [4,5]: R1331 (near-infrared albedo at 1.331 µm), BD1900_2 (1.9 µm band depth), BD1400 (1.4 µm band depth), D2300 (2.3 µm band depth), and D2200 (2.2 µm band depth). These absorption bands are known to represent the most common VNIR alteration signatures on Mars [2]. R1331 was used to determine whether there are clear morphological features associated with observed alteration signatures.

A value of 0, 1, or 2 was assigned to each parameter for each CRISM image, with 0 representing no obvious spatial patterns in parameter values, 2 representing clear spatial patterns, and 1 representing ambiguous signatures. Parameter scores were then summed to derive a relative ranking of alteration mineral detection confidence. Summed scores ranged from 0 to 10.

Results: Our results are summarized in **Table 1** and are consistent with the hypothesized reduction of alteration phases with time in martian geologic history. 39% of CRISM images over Noachian landscapes scored 5 or higher in the total summed parameter scores, while the percentage decreased to 33% and 17% for Hesperian and Amazonian images, respectively.

Discussion: Previous investigations regarding the distribution and age of altered terrain on Mars used the entire CRISM database to derive their results [e.g., 2]. However, CRISM does not randomly select locations to image on the martian surface and are instead targeted over regions of interest, which tend to be older and more heavily eroded landscapes. This statistical investigation of alteration signatures in randomly selected CRISM images, therefore, is an effective validation of our widely accepted understanding that ancient Mars is more altered than modern Mars.

Despite our best attempts to accurately cross-compare the presence/absence of alteration phases in landscapes of different ages, certain potential confounding factors are simply unavoidable. For example, rates of physical erosion and exposure of subsurface units significantly decreased from the Noachian into the Amazonian [8]. This suggests that images over Amazonian landscapes are less likely to contain erosional windows into the

Table 1. Catalog of CRISM images investigated in this study, aggregated by landscape age and the sum of CRISM parameter scores.

Surface Age	Total CRISM Images	< 2 "Probably Not Interesting"	3-4 "Maybe Interesting"	5-6 "Probably Interesting"	≥ 7 "Likely Interesting"
Noachian	67 (40.4%)	25 (37.3%)	16 (23.9%)	9 (13.4%)	17 (25.4%)
Hesperian	51 (30.7%)	22 (43.1%)	12 (23.5%)	4 (7.8%)	13 (25.5%)
Amazonian	48 (28.9%)	24 (50.0%)	16 (33.3%)	3 (6.3%)	5 (10.4%)

subsurface that may expose alteration phases underneath more modern mantling deposits. In addition, the majority of Amazonian-aged landscapes on Mars are mantled in optically thick dust and were excluded from this investigation. This results in more spatial clustering of Amazonian-aged observations than either Noachian- or Hesperian-aged CRISM images, which is apparent in **Figure 1**. This clustering has the potential to inaccurately skew our statistics by concentrating observations in areas without exposed alteration phases. Lastly, while efforts were made to identify erosional windows into older geologic units, it is possible that alteration signatures observed in younger terrains should actually be categorized in older geologic units.

Implications and Future Work: Our investigation confirms (to the extent possible) that the environments on ancient Mars were more conducive to aqueous alteration than those on modern Mars. While seemingly unsurprising, this result helps to validate this commonly accepted alteration paradigm that has driven our understanding of martian surface and subsurface environments for decades. Additional work would be required to validate the geologic context and compositional nature of these alteration phases.

References: [1] Bibring et al. (2006), *Science* **321**, 10.1126/science.1122659. [2] Carter et al. (2013), *JGR-P* **118**, 10.1029/2012JE004145. [3] Murchie et al. (2007), *JGR-P* **112**, 10.1029/2006JE002682. [4] Pelkey et al. (2007), *JGR-P* **112**, 10.1029/2006JE002831. [5] Viviano-Beck et al. (2014), *JGR-P* **119**, 10.1002/2014JE004627. [6] Christensen et al. (2001), *JGR-P* **106**, 10.1029/2000JE001370. [7] Tanaka et al. (2014), *USGS Sci. Inv.* **3292**. [8] Golombek et al. (2006), *JGR-P* **111**, 10.1029/2006JE002754.

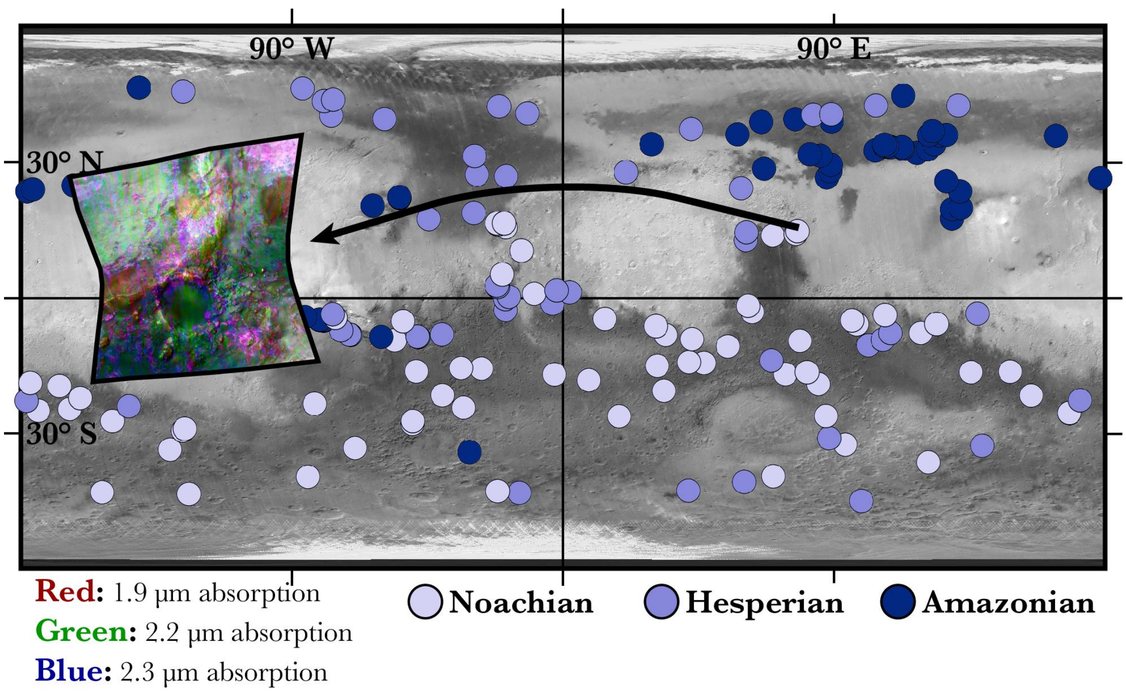

Figure 1. Global map of all randomly studied CRISM images from this investigation. Subset shows one particular image (FRT00018524) with three spectral parameters, highlighting an image of interest with clear alteration signatures. Background is TES albedo overlain on MOLA hillshade.