POLAR OPPOSITES: DISTINCT ALTERATION MINERALS WITHIN THE NORTH AND SOUTH POLAR LAYERED DEPOSITS (PLD) AND IMPLICATIONS FOR AMAZONIAN AQUEOUS HISTORY.
P. Sinha[1] and B. Horgan[1], [1]Purdue University (sinha37@purdue.edu).

Introduction: Mars today is cold and dry, although liquid water might occur episodically as dense brines or melt. Studying the nature and distribution of hydrated/altered minerals within the north and south PLD would reveal the history of water activity during Amazonian Mars, where fluids are saline, acidic, and rare [1]. Different alteration minerals are formed in unique redox and geochemical environment, so, their detection at the PLD directly influences our understanding of the habitability conditions in this period.

Previously, sulfates have been detected in the north polar sand sea, suggesting the recent presence of liquid water in north polar terrains [2-4]. The glass in the sand sea also appears to have been subjected to aqueous alteration, most likely acid leaching to form silica rinds [5]. Hydrated sulfates are widespread in the sediments on the NPLD, which could either indicate aqueous alteration of NPLD lithics [4] or that the salts are atmospheric precipitates that accumulated in sublimation lags [6,7]. Observations from the Phoenix lander support the presence of active perchlorate brines in polar soils, including transient liquid droplets, dielectric permittivity consistent with brines, and clumping of perchlorate-bearing soils [8-10]. A possible perchlorate absorption band has been detected based on ~2.15 µm in NPLD sediments [6]. However, recent studies have shown that this could also be an artifact in CRISM I/F data [11].

At southern high latitudes, detection of hydrated sulfates suggests aqueous activity also occurred in the south polar region of Mars [12-13]. However, sulfates and perchlorates have not been detected on or around the SPLD. Instead, weak hydration from smectites has been detected in SPLD sediments [14], but it is unknown whether they formed in situ or are sourced from nearby Noachian/Hesperian bedrock. These observations suggest that the poles may have experienced different aqueous alteration histories, but additional work is needed to understand the occurrence and distribution of alteration minerals within both north and south PLD.

In this study, we attempt to look for diversity in secondary minerals at the PLD. We hypothesize that the alteration histories of NPLD and SPLD may be different due to many factors. The SPLD lies over the southern highlands and has much higher elevation than its northern counterpart which results is a different atmospheric condition in both regions. Axial tilt influencing temperature and duration of winter drives accumulation and ablation differently at the two PLD. Moreover, SPLD being older provides a geologic window to look deeper into climatic history of Amazonian Mars [15,16].

Methods: CRISM MTRDR and TRR3 hyperspectral image cubes from both north and south PLD (**Figure 1**) were analyzed using the CRISM Analysis Toolkit (CAT). The 18-40 m/pixel data is examined at visible and near- infrared wavelengths (VNIR, 0.7-2.6 µm) for presence of altered minerals like oxides, salts, smectites, zeolite, and leached glass (**Figure 2**): ferric oxide (hematite) cause an strong absorption at 0.86 µm; sulfate salts show hydration bands at 1.44 and 1.92 µm along with a spectral shoulder at 2.4 µm; smectites also display hydration bands in addition to have a hydroxylation band between 2.1 and 2.4 µm whose center shifts depending on the element bonded with an hydroxyl ion; zeolite have an absorption band centered around 2.5 µm along with hydration bands at 1.44 and 1.92 µm; and leached glass which shows strong blue spectral slope with negligible to weak ferrous iron absorption at 1 and 2 µm.

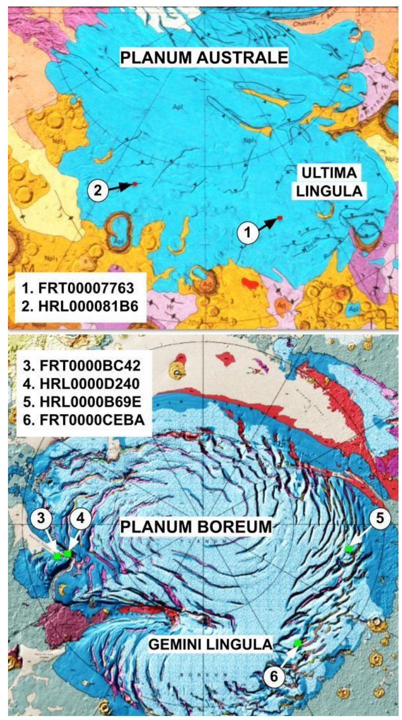
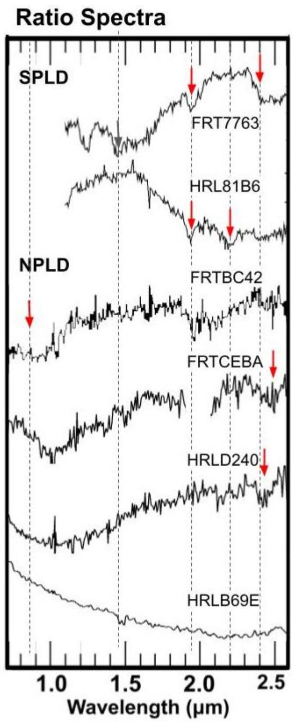


Figure 1: *Location of CRISM images used in this study on geologic map of SPLD (top) and NPLD (bottom).*

To determine the spectral signature of alteration minerals at identified regions of interest (ROI), the reflectance spectrum is ratioed against a neutral spectrum. A reference/neutral spectrum is selected such that upon ratioing it suppresses the effects of ice, dust, and mafic minerals in the region. The ratio spectrum emphasizes the spectral signatures of alteration minerals that occur as mixtures with other lithic sediments.

Results: The technique developed to select neutral spectrum for ratioing reflectance spectra was used successfully in extracting alteration signatures. However, the signatures of alteration minerals were weak and noisy as these minerals are likely present in lower concentration and do not spectrally dominate the VNIR wavelengths. At the NPLD, possible alteration minerals detected were hematite, sulfate, zeolites, and leached glass, while at the SPLD the possible minerals detected were sulfates and Al-clays (e.g., smectite) or hydrated silica (**Figure 2**). Previous SPLD analysis detected possible Al- and Fe/Mg-clays [9].



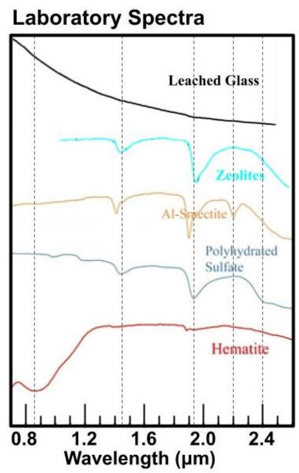


Figure 2: *Spectra containing alteration signatures from sulfates, smectites, hematite, and leached glass detected at the PLD (right) along with their lab spectra (left).*

Discussion: Search for alteration signatures shows that oxides, salts, and clays are present within the PLD. But detection of sulfate were most frequent, hence, they appear to be most widespread spectrally resolvable alteration mineral in the polar regions. The origin of polyhydrated sulfates like gypsum is attributed to either atmospheric precipitation or alteration of lithics within the PLD which require some aqueous activity at minimum which could be either due to astronomical climate forcing or stochastic processes like impacts and volcanism or cyclical freeze-thaw in the subsurface. Sulfates from either source likely concentrate within the lag deposits where their spectral signatures are most dominant.

Detection of smectites at the SPLD is of special interest as smectites previously detected at the SPLD margins (FRT000076E1; -82.42,306.08) have been proposed to be an alternate cause of bright MARSIS radar reflections from the subsurface [14]. The smectite detections made in this study lie over the SPLD (CRISM map; **Figure 3**). The origin/occurrence of clays at the SPLD is not well known, however, SPLD is known to be surrounded by clay-rich Noachian terrain that likely underlie the SPLD causing the radar reflection. Stochastic processes like impacts in the altered terrains may have gardened the SPLD with smectites as well. Alternately, the origin of clays within the SPLD could suggest a different alteration environment, perhaps still at low water-rock ratios but less acidic and/or more persistent.

So far, our search for alteration minerals within the NPLD has not led to any detection of clays/smectites or silica, rather, the highly oxidized ferric mineral hematite was detected along with sulfates, which suggest an acidic and/or oxidizing as well as evaporative environment similar to modern day conditions on Mars.

Detection of weathered glass, which if altered in situ at the NPLD, suggests recent aqueous activity in the NPLD. Sulfates detected within the NPLD may have formed by alteration of lithics entrained in ice [4,6,7] which requires some activity of liquid water. The process of weathering by acid-leaching occurs in the presence of liquid water that causes surficial alteration creating weathering rinds around lithic sediments [17]. At the low temperatures of the NPLD, liquid water brines can persist as thin film surrounding lithic sediment which is likely responsible for leaching of Fe-bearing glasses [18]. The degree of aqueous activity and thus the habitability of Mars polar terrains is perhaps controlled by climate change caused by astronomical forcing or due to discrete events of mantling by impact ejecta or volcanic ash. The search for alteration signature within the PLD is in its initial stage and future work will look for other secondary minerals such as perchlorates, hydrated silica, etc., within the PLD.

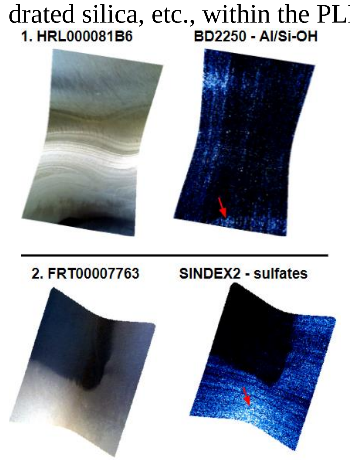


***Figure 3**: SPLD CRISM true color image and alteration parameter map.*

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