

VNIR SPECTRAL PROPERTIES OF FELSIC ROCKS: IMPLICATIONS FOR MARS DETECTIONS

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Introduction: Felsic (higher silica or feldspar) rocks are known or hypothesized to be present on the Earth, Moon, Mars, and Venus, and are inferred to represent magma evolution during early crust formation or later igneous activity [1-4]. Absorption bands consistent with plagioclase feldspar have been observed on Mars at multiple locations [5-9] using visible to near infrared (VNIR; $\sim 0.5\text{-}2.6\ \mu\text{m}$) hyperspectral orbital data from the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM; 10). Plagioclase has an absorption feature at $\sim 1.25\ \mu\text{m}$ due to Fe^{2+} substitution for Ca^{2+} in its crystal lattice [12], but this absorption is weak compared to other mafic minerals, so it was thought that the $1.25\ \mu\text{m}$ feature only appeared when plagioclase was highly concentrated ($>85\ \text{wt}\%$; 13-15). Thus, some studies have interpreted the Mars detections as indicating plagioclase-rich felsic rocks, including plutonic anorthosites [5], evolved felsic rocks [6], or plagioclase-dominated ($>85\ \text{wt}\%$) early crustal material [7]. However, others argue that some locations show mid-IR spectral properties that are more consistent with more primitive lavas with a much higher mafic mineral content (up to 50%) and hypothesize that the signature originates from large plagioclase crystals [8,9]. This would imply a significantly different lithology and geological evolution for those terrains and the Martian crust more generally than if they were more evolved volcanic rocks or crustal intrusions.

One of the limitations of past studies is that models for plagioclase detection were based on studies of granular mixtures rather than whole rocks, which can exhibit mineralogical and petrological complexity that can strongly influence their spectral signatures [11]. Lab analysis of whole rocks is needed to assess the influence of grain size, other Fe-bearing minerals, and matrix characteristics on observed spectra, which is intimately tied to interpretations of rock outcrops observed in orbital data. In order to better understand petrologic constraints on plagioclase detection limits as well as felsic rock VNIR spectral characteristics more generally, we analyzed a diverse suite of intrusive and extrusive felsic rocks using both VNIR reflectance spectra and thermal infrared (TIR; $400\text{-}1200\ \text{cm}^{-1}$) emission spectra. These evaluations help provide context for how we can interrogate felsic terrains on other planets from orbit.

Methods: We obtained VNIR spectra from 18 fresh intrusive samples (tonalite, monzonite, diorite, granodiorite, granite) and 15 extrusive samples (rhyolite, obsidian, ignimbrite, dacite, andesite, basaltic andesite) at Purdue University using an Analytical Spectral Devices QualitySpec Trek spectrometer. The Trek wavelength range is $0.35\text{-}2.5\ \mu\text{m}$, similar to the CRISM spectral

range [10] used in all aforementioned Mars analyses. The samples in our study represent a broad range of silica and plagioclase content. Importantly, almost all intrusive samples are unaltered, and spectra were obtained on fresh faces of the samples. We analyzed mineral absorption bands by determining the position of the plagioclase band center, and grouped rocks based on grain size (coarse, medium, fine) to assess variability between phaneritic, porphyritic, and aphanitic samples.



Figure 1: Granodiorite (left), tonalite (middle), and granite (right) from intrusive sample suite. Shown in Figure 2 left panel as green, black, and green spectra respectively. These range from $\sim 60\text{-}72\ \text{SiO}_2\ \text{wt}\%$ and $\sim 15\text{-}45\ \text{plag}\ \text{wt}\%$.

Results: Plagioclase absorption features are surprisingly common in our intrusive samples and appear to be stronger (higher band depth) in coarser-grained samples (Figure 1 left panel). Coarse samples bear plagioclase crystals $\sim 1\text{-}10\ \text{mm}$ in size. Most intrusive samples have a broad absorption feature centered near $1.2\text{-}1.3\ \mu\text{m}$, consistent with plagioclase, and larger plagioclase grain sizes tend to cause deeper absorption features, particularly in granodiorites. In most samples, complex absorption features between 2.2 and $2.4\ \mu\text{m}$ are also observed, likely due to primary or secondary hydrated minerals such as mica, hornblende, or smectite. Extrusive samples in our suite do not exhibit a $1.2\text{-}1.3\ \mu\text{m}$ feature.

The granodiorites ($\sim 64\text{-}68\ \text{SiO}_2\ \text{wt}\%$) have the most distinct $1.2\text{-}1.3\ \mu\text{m}$ feature. This is less consistent in granites, especially the K-feldspar-rich example, which display little evidence for a $1.2\text{-}1.3\ \mu\text{m}$ feature. The tonalites ($\sim 60\text{-}65\ \text{SiO}_2\ \text{wt}\%$, plag-rich) bear a distinct $1.2\text{-}1.3\ \mu\text{m}$ feature, but it tends to be shallower and broader than the $1.2\text{-}1.3\ \mu\text{m}$ feature in granodiorites and may be more consistent with a broad charge transfer band caused by Fe-bearing mica or weathering products. Among the granites ($\sim 70\text{-}78\ \text{SiO}_2\ \text{wt}\%$), the coarser-grained samples and one sample at the granodiorite-granite border display the strongest $1.2\text{-}1.3\ \mu\text{m}$ absorption, and in the fine-grained granite there is no obvious absorption feature.

Discussion: These results show that felsic rocks may be more detectable in VNIR spectra than

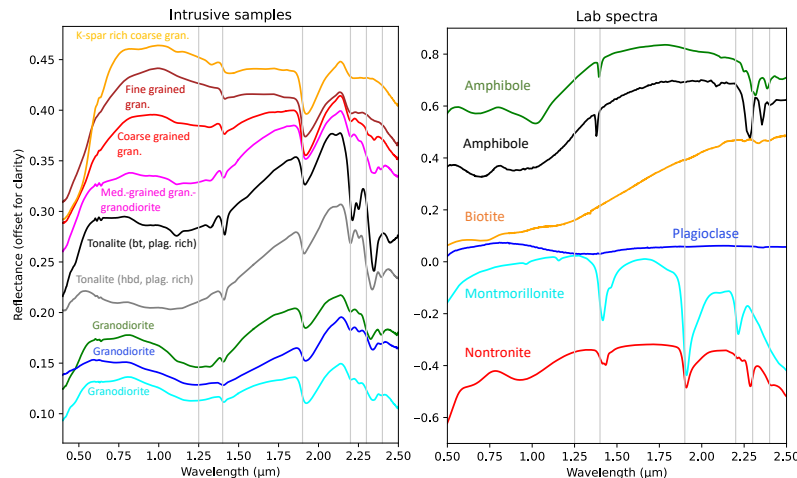


Figure 1: *Left:* Spectra from a subset of the intrusive sample suite, where sample label color corresponds to spectrum color. The grey lines align with plagioclase absorption (1.25 μm) and hydration features (1.4, 1.9, 2.2, 2.3, 2.4 μm). The granodiorites (bottom 3 spectra) display a stronger 1.25 μm band than the granites (top 3 spectra), likely due to both larger grain size and higher plag wt%. *Right:* Lab spectra of minerals common in our sample suite (top four) and common clays on Mars (bottom two). Source: WWU VISOR/University of Winnipeg.

previously recognized. This is best supported by the granodiorites since their spectra (Figure 1 left panel, bottom three spectra) show the most distinct plagioclase detection at 1.3 μm even though the rocks contain <35 wt% plagioclase. We hypothesize that grain size is a primary constraint on this detection, in that larger plagioclase grain sizes cause more distinct absorptions [9]. However, broad absorption by other Fe-bearing minerals like mica at 1.2-1.3 μm in some samples complicate interpretation. [9] propose that plagioclase can be detected even when 50 wt% mafic materials are present, if the rock is dominated by large plagioclase crystals hosted in a fine-grained mafic ground mass. Our results support detection of plagioclase at lower wt%, but the lithologies of our samples are far different from this description, and further study is needed into the spectral effects of coarse plagioclase crystals mixed with mafic minerals [9,16].

When present, the plagioclase band center range in our samples (1.2-1.3 μm) is similar to most detections of plagioclase on Mars: 1.25-1.35 μm [5], 1.2-1.25 μm [9], 1.2-1.35 μm [7]. Band centers from some detections in [6] are shifted to lower band center, 1.15 μm , and care must be taken to differentiate these detections from Fe-bearing glass [17] and coarse olivine [18].

The spectra in the left panel of Figure 1 show complex absorption features, especially at longer wavelengths (\sim 2.0-2.5 μm), and absorptions associated with hydration at 1.4 and 1.9 μm . These absorption features are consistent with contribution from primary hydrated minerals like micas and thus should be considered when interpreting Martian spectra. However, surface weathering generates abundant secondary hydrated minerals on

the surface of Mars such as hydrated silica and smectite that have similar absorption features [19]. Alteration features observed in the spectra of [5] and [9] appear similar to smectite absorption bands (Figure 1 right panel, red and cyan spectra). Our spectra tend to have a narrower 2.2 μm absorption and deeper 2.3-2.4 μm absorption that more closely resembles amphibole (Figure 1 right panel, green and black spectra). Thus, it may be possible to distinguish primary and secondary hydration bands from one another in our sample set, but comparisons to other clay minerals are needed.

In some Mars observations, the spectra are minimally altered and do not bear absorption features associated with hydration, which differentiates them from our terrestrial samples and may imply a higher weight percentage of plagioclase feldspar as other minerals' absorptions are absent [6,7]. Among current hypotheses, including plag-rich plutonic rocks and coarse plagioclase in a mafic lava [5-9], coarse grain size may be critical in plagioclase detection, supported by our results.

Future Work: We will analyze rock microtexture and chemistry to provide a comprehensive view of spectral character which we plan to obtain with thin sections and XRF analysis. Quantitative absorption band analysis will help us interpret individual mineral bands. We have collected a suite of thermal IR spectra to assist with VNIR interpretations and provide quantitative mineralogy, and these spectra will be convolved with THEMIS data to compare to Mars detections of felsic materials.

References: [1] Bandfield et al., 2000, *Science*, 287(5458), 1626–1630. [2] Gilmore et al., 2015, *Icarus*, 254, 350–361. [3] Glotch et al., 2010, *Science*, 329(5998), 1510–1513. [4] Hamilton et al., 2001, *JGRP*, 106(E7), 14733–14746. [5] Carter & Poulet, 2013, *Nat. Geo.*, 6(12), 1008–1012. [6] Wray et al., 2013, *Nat. Geo.*, 6(12), 1013–1017. [7] Phillips et al., 2022, *Geology*, <https://doi.org/10.1130/G50341.1> [8] Rogers & Farrand, 2022, *Icarus*, 376. [9] Rogers & Nekvasil, 2015, *GRL*, 42(8), 2619–2626. [10] Murchie et al., 2007, *JGRP*, 112. [11] Scudder et al., 2021, *Icarus*, 359, 114344. [12] Adams and Goullaud, 1978, *LPSC IX*, 2901-2909. [13] Cheek et al., 2013, *JGRP*, 118(9), 1805–1820. [14] Cheek & Pieters, 2014, *Am. Min.*, 99(10), 1871–1892. [15] Carli et al., 2014, *Icarus*, v. 235, p. 207–219. [16] Eggers et al., 2021, *JGRP*, 126(2), 1–17. [17] Horgan et al., 2014, *Icarus*, 234, 132–154. [18] Viviano et al., 2019, *Icarus*, 328, 274-286. [19] Payré et al., (2022). *GRL*, 49, e2022GL099639.