**INFRARED SPECTRAL IDENTIFICATION OF UNUSUALLY FELDSPAR-RICH ROCKS ON MARS.**

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**Introduction:** Feldspar-rich, mafic-poor rocks dominate Earth's upper continental crust and the ancient lunar highlands. On Earth, felsic rocks (>65% $SiO_2$), including granite and its volcanic equivalent, rhyolite, form most commonly in subduction zones through partial melting or fractional crystallization in the shallow crust. Anorthosite (>90% feldspars) forms in low-density cumulate layers in a slowly cooling mafic magma chamber, or on a global scale (e.g., on Earth's Moon) in a primordial magma ocean.

Mars appears to lack plate tectonics, yet has experienced too much erosion and burial to retain abundant surface evidence for any early magma ocean. The inferred dominance of basaltic compositions [1] is thus relatively unsurprising. Some regions spectrally resemble andesite [2], but have alternatively been interpreted as weathered basalt or glass [3,4]. Localized quartz was first attributed to evolved magmas [5] but can instead be explained as a secondary phase formed hydrothermally or via diagenetic maturation of opaline silica found in the same locations [6,7]. The only widely accepted example of intermediate-to-felsic igneous rocks on Mars is a dacitic unit in the Nili Patera caldera of Syrtis Major, identified in the thermal IR [8].

Here we describe a new method for identifying very mafic-poor materials on Mars, present detections, and discuss possible interpretations and implications.

**Data and Methods:** We used data from the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM). Spectral features in CRISM's 0.4–3.9 μm wavelength range result mostly from electronic transitions in transition metals (primarily Fe) and vibrational modes of light molecular groups such as OH, $H_2O$, or $CO_3$. Pure quartz and feldspar are nominally undetectable, but some feldspars exhibit a broad absorption centered at ~1.25–1.3 μm due to minor substitution of $Fe^{2+}$ for $Ca^{2+}$. This absorption is typically much weaker than the ~1 μm absorption of Fe-rich phases such as olivine and pyroxene, so it is detectable only in very feldspar-rich rocks with <5% associated mafics (as seen in some areas on the Moon [9]). Such rocks were not expected on Mars, so none of CRISM's standard mapping parameters is designed to identify them. Yet they were found in small outcrops in Xanthe Terra (N. of Valles Marineris) [10] and elsewhere [11].

We sought broader exposures to better characterize the distribution and physical properties of these materials. We focused our analyses on Syrtis Major (the only large Martian volcano whose bedrock compositions are not obscured by mantling dust) and northeast Noachis Terra in the southern highlands, which has the densest concentration of exposed intercrater and crater-floor bedrock on Mars [12,13]. Other regions may contain analogous materials beneath surficial dust.

**Noachis Terra:** In broad outcrops spanning tens of km$^2$ each across several large crater floors and intercrater plains in Noachis Terra (Fig. 1), a ~1.3 μm absorption band is the strongest spectral feature observed in the 0.7–2.6 μm range (Fig. 2). We attribute this feature to $Fe^{2+}$ in feldspar. The only other minerals in our spectral libraries with similarly broad absorptions centered at 1.23–1.32 μm are $Fe^{2+}$-bearing garnets, such as almandine (Fig. 2b). However, such garnets have a comparably broad (and half as deep) absorption at ~1.7 μm, which is not observed in our CRISM spectra. The lack of any absorptions near 1 μm (Fig. 2a) suggests very low pyroxene and olivine abundances, possibly <2% [9]. Spectrally these rocks resemble lunar anorthosites, but they could alternatively be truly felsic, as CRISM cannot uniquely constrain their quartz content nor Ca,Na,K-feldspar composition (Fig. 2b).

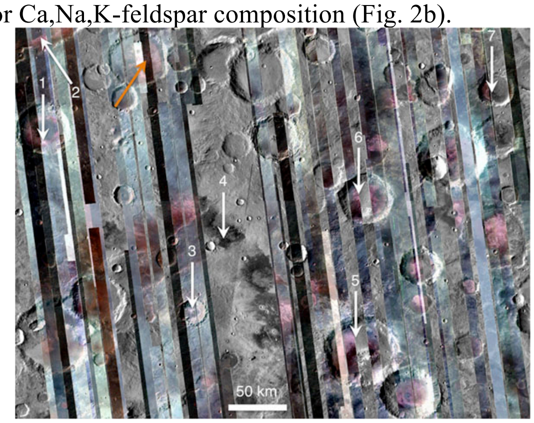


**Figure 1.** Felsic materials (bright pink) in Noachis Terra. CRISM multispectral mapping data overlain on THEMIS daytime IR mosaic. Orange arrow points to source area for gold and magenta spectra in Fig. 2b; white arrows indicate other locations where higher-resolution CRISM data confirm feldspar-rich materials. Image is centered at 22.8°S, 44.6°E.

In one ~52 km crater (Fig. 1, orange arrow), aqueous activity both before and after emplacement of the felsic unit is evidenced by Al- and Fe/Mg-smectites in the pre-existing crater wall rocks, and sinuous ridges (interpreted as inverted fluvial channels) extending across the crater floor and overlying the bright feldspar-rich unit [14]. Some portions of this unit show evidence of minor alteration via absorptions at ~1.9 and 2.4 μm, consistent with hydrated sulfates or certain zeolites; other portions appear relatively unaltered.

Feldspar-rich exposures in Noachis Terra are found across an area of at least ~150,000 $km^2$. Some of these outcrops (e.g., arrow 4 in Fig. 1) correspond to a “red unit” identified in decorrelation-stretched images from the Thermal Emission Imaging System (THEMIS) [12]. This high-thermal inertia unit was unresolvable by hyperspectral imagers before CRISM, but THEMIS data implied a relatively mafic-poor, high-silica, and/or sulfate-rich composition [12]. CRISM reveals these to be feldspar-rich materials with very low mafic abundances, variably altered to hydrated phases (sulfates?).

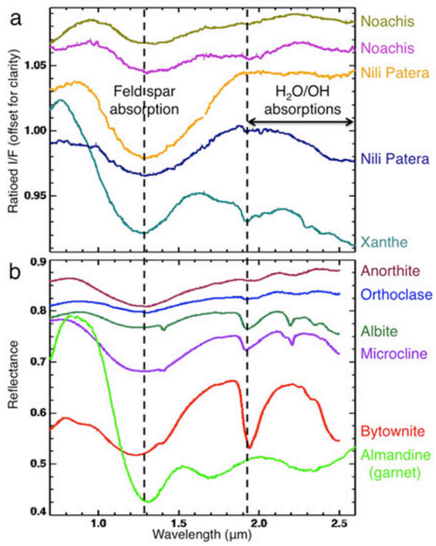


**Figure 2.** (a) CRISM spectral ratios from FRTs 8F08, 82EE, and HRL 927F. (b) USGS library spectra of feldspars.

**Syrtis Major:** Feldspar-rich rocks are exposed at the lowest elevations within the Nili Patera caldera, in bedrock with one of the highest thermal inertias measured on Mars. This outcrop is only ~2 km from the dacitic flow of [8]. Small remnant mounds scattered across the outcrop suggest it was once buried beneath at least several meters of eroded material. Opaline silica deposits are observed nearby [15].

The association of dacites with more felsic rocks is common on Earth and can be produced by partial melting or fractional crystallization. To test an analogous origin for the Nili Patera materials, we performed crystallization calculations based on thermodynamic phase equilibria. We used several dacitic and intrusive equivalents from Earth and a Mars Pathfinder “andesite” for starting compositions, each comparable in mineralogy to the Nili Patera dacite after renormalization to include only its primary phases. After fractional crystallization, extracted melts were more silica-rich (typically >70 wt.% $SiO_2$) than their parent magmas, matching the low pyroxene abundances required by CRISM.

**Implications:** If the Nili Patera rocks are indeed felsic, then the range of silicic rocks observed there is similar to the compositional diversity seen on Earth at sites of prolonged magmatic activity, in contrast with the current paradigm of minimal Martian magma evolution [1]. Crater counts [16] and stratigraphic relations imply an Early Amazonian age (~3–2 Ga) for the felsic rocks if they formed at the surface (as rhyolitic lava or ash), or they may be younger if formed intrusively and later exhumed, a dichotomy hard to resolve from orbit.

Some of the felsic outcrops in Noachis (e.g., arrow 5 in Fig. 1) have been catalogued in a global population of bedrock crater floors, hypothesized to have formed through inflationary volcanism following impact-generated fractures in basement rock [13]. If such a process formed felsic rocks, then these must have been derived from a high-Si reservoir at depth. Alternatively, feldspar-rich rocks associated with fluvial systems and/or phyllosilicates (as in Noachis) might have formed via selective alteration of intermediate or even mafic primary lithologies. Under acidic conditions, feldspars alter much more slowly than glass, olivine or pyroxene. On a world with minimal primary quartz, perhaps fluvially transported sediments became enriched in feldspars (vs. quartz on Earth), if fluid exposure was limited in duration. However feldspar-rich rocks formed, their alteration would have produced more Al/Si-rich secondary phases than would the alteration of basaltic precursors, perhaps explaining some detections of Al-clays and silica across Mars [e.g., 6].

Our results provide global context for the Curiosity rover’s inference of felsic materials in Gale crater [17].

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