SID: THE MOST FRACTIONATED MARTIAN MAGMA TO DATE AND ITS CRUSTAL EVOLUTION.

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Introduction: The Jezero crater floor campaign of the M2020 Perseverance rover mission [1] investigated and sampled a suite of igneous lithologies, including olivine cumulate of the Séitah fm. [2] and evolved, high-Fe basaltic lavas of the Máaz fm. [3,4]. The last outcrop examined, named Sid, belongs to the Ch'al mb. of Máaz fm., a stratigraphically high, aerially extensive, cratered unit. Abrasion of Sid (target name Alfalfa) revealed light-toned laths surrounded by a red-brown matrix. Paired samples (Hahonih and Atsah) were collected from Sid for their geochronologic potential for crystallization and exposure ages to constrain the history of Jezero crater and crater count calibration [5].

We here present textural, geochemical, and mineralogical results of Alfalfa by the Planetary Instrument for X-ray Lithochemistry (PIXL) and Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals (SHERLOC) instruments on Perseverance. Alfalfa represents the most evolved (fractionated) Martian magma examined to date, and we discuss its relationship to other crater floor rocks and petrogenesis in the crust.

Methods: PIXL is an x-ray fluorescence (XRF) spectrometer that maps fine-scale (~120 µm spot, PMC) elemental compositions of martian surface materials. Elements reported for individual spots include Na to Fe. For bulk sums of XRF spectra, some trace element concentrations (e.g., Sr, Zn, Zr) may also be reported when detected [6]. X-ray diffraction (XRD) peaks may also be present on individual XRF spectra (PMCs) of coarse crystalline materials (grain size >50 µm); XRD peaks provide textural information [7], but are corrected out of XRF spectra. PIXLISE [6] is data visualization software to analyze x-ray spectral, spatial, and compositional variations. The Alfalfa PIXL scan (sol 369) was a 7x7 mm^2 map, yielding 3258 total PMCs.

Images by SHERLOC Watson and ACI (Autofocus Context Imager) cameras [8] and PIXL's MCC (Micro Context Camera) provide context for PIXL and SHERLOC scans. SHERLOC couples microscopic images with scans by a deep UV laser to obtain spectra of fluorescence and Raman emissions for identification of organics, chemicals, and minerals [8]. Scans were processed to remove backgrounds, normalized, and compared to spectra from analogue laboratory instruments (e.g., MOBIUS) of reference materials (including silicate minerals like feldspars).

Results: PIXL and SHERLOC scans of Alfalfa indicate that Sid includes both crystalline and amorphous (or poorly crystalline) components.

Igneous Texture. PIXL element maps of Alfalfa reveal a porphyritic texture. Figure 1, and RGB element map, shows 1-5 mm laths of plagioclase feldspar (light green), Fe-rich augite (<1 mm, purple), and Fe-silicate + magnetite (altered olivine, red) in a fine-grained K-rich matrix (dark green), which we interpret as igneous groundmass.

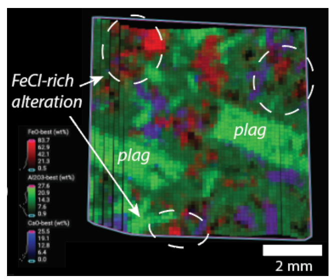

Fig. 1. PIXL RGB map. FeO red, Al_2O_3 green, CaO blue.

Other late-stage igneous minerals include apatite (blue), Fe-oxide (likely Ti-magnetite, red) and crystalline SiO_2. Relative to other Máaz PIXL targets, Alfalfa contains the highest proportion of plagioclase and K-rich groundmass and lowest of pyroxene.

Alteration. Igneous phases are variously altered in Alfalfa. Iron-rich olivine (i.e., fayalitic) is locally altered to a fine-grained, poorly crystalline assemblage of Fe-bearing silicates (with high Cl and SiO_2 from 22-76 wt%) and magnetite. The groundmass is altered significantly too, with abundant Cl (up to 5 wt%); ~11% of the matrix PMCs are aluminous with Chemical Index of Alteration (CIA) values >50, which implies locally intense alteration. Some PMCs in the feldspar phenocrysts contain Cl, SO_3, and FeO, suggesting they are also altered locally.

Bulk Chemistry. The bulk elemental composition of low-alteration regions (<2 wt% SO_3 and <4 wt% Cl) in Alfalfa is trachy-andesite (Fig. 2). Low concentrations of igneous compatible elements (Mg, Cr) and high Fe and Al among all Máaz targets (and Alfalfa in particular) are consistent with their formation via fractional crystallization of basaltic parental magma(s). The Alfalfa Mg# (molar MgO/(MgO+FeO)*100) is notably low (11), indicating extensive fractionation. Other Máaz PIXL targets are basaltic to trachy-basaltic with Mg# ranging from 34.5-13.8. For comparison, the Mg# of the most evolved basaltic shergottite meteorite, Los Angeles, is 23-25 [9].

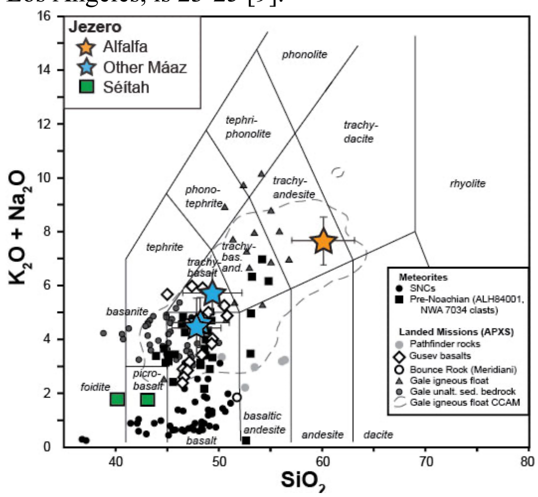

Fig. 2. Total alkali vs. silica diagram for Mars igneous rocks [10-16], including low alteration, bulk compositions Máaz [4] and Séítah [2,18] fm. PIXL targets.

Mineral chemistry. Alfalfa contains highly evolved mafic minerals, including Fe-rich augite micro-phenocrysts (En_{07} Wo_{39} Fs_{54}) that, like in many Máaz targets [3,4], plot in the 1 kbar "forbidden zone" [18] (Fig. 3) and within the range of last crystallizing pyroxenes of the Los Angeles meteorite [19]. No orthopyroxenes have been identified by PIXL.

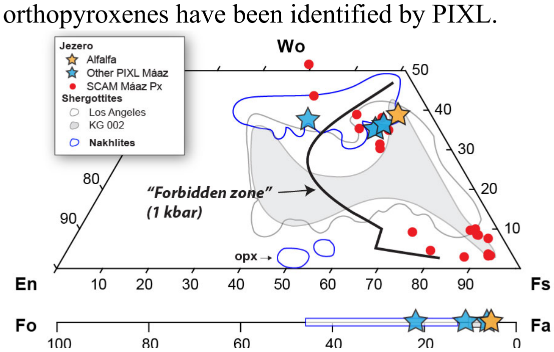

Fig. 3. Pyroxene quadrilateral and olivine binary plots of mineral endmember compositions of Máaz fm. targets examined PIXL [4] and SuperCam (SCAM) [3] and select, evolved Martian meteorites [19-21].

Alfalfa feldspars yield good stoichiometry in low alteration regions (An_{29} Or_{03} Ab_{68}), similar to those in other Máaz rocks [3,4]. SHERLOC Raman spectra on the feldspars were of two types [c.f., 22]: those in the matrix with peak centers at 1030-1110 cm^{-1}, consistent with alkali feldspar, and the larger lath crystals with peak centers at 1010-1030 cm^{-1}, consistent with crystalline plagioclase [23], and complementary to PIXL.

The two larger feldspar phenocrysts (Fig. 1) are highly ordered, single crystals, as indicated by their numerous diffraction peaks in PIXL x-ray spectra. The feldspars are normally to oscillatory zoned with respect to Anorthite (An) content (Fig. 4a) and contain relatively large holes (~1 mm) and an embayment (>1 mm). A low Al_2O_3 rim (<50 µm grain size) surrounds the feldspars, with CaO and FeO variations that suggest it is a finely crystalline mixture of feldspar, augite, and Fe-silicate, distinct from the more homogeneous K-rich matrix. The larger feldspars are therefore not in thermal or chemical equilibrium with the K-rich groundmass.

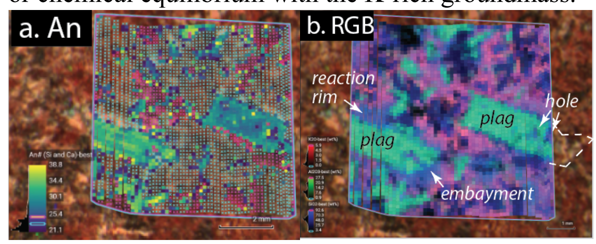

Fig. 4. Alfalfa PIXL maps showing a) An content in feldspar (An 25-40) and b) RGB. K_2O red, Al_2O_3 green, and SiO_2 blue.

Discussion and Conclusion: The very low bulk Mg# and notably high Fe contents of the augites (Fig. 3) indicate Ch'al mb. lavas, represented by the Alfafa target as well as other Máaz rocks are products of high degrees of fractional crystallization. Complementary, relatively high-Mg crystalline lithologies would have formed as a consequence of this process. The large feldspars with disequilibrium textures in Alfalfa (Fig. 4b) suggest its Ch'al parental magma ingested feldspar crystals that likely formed in the crust, possibly by fractional crystallization of earlier Máaz magmas.

Acknowledgments: The M2020 mission and PIXL are supported by NASA. Schmidt and Herd are funded by Canadian Space Agency M2020 PS grants.

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