

**REGOLITH ON THE RIM OF JEZERO CRATER AND ITS RELEVANCE TO HUMAN EXPLORATION OF MARS.** A. O. Shumway<sup>1</sup>, S. J. VanBommel<sup>2</sup>, M. M. Tice<sup>3</sup>, K. Ramo<sup>4</sup>, V. Hoogland<sup>5</sup>, M. W. M. Jones<sup>5</sup>, A. T. Treiman<sup>6</sup>, Y. Liu<sup>7</sup>, J. A. Hurowitz<sup>4</sup>, B. C. Clark<sup>8</sup>, N. Martin<sup>9</sup>, C. C. Bedford<sup>9</sup>, G. D. McDonald<sup>10</sup>, S. A. Connell<sup>9</sup>, J. M. Madariaga<sup>11</sup>. <sup>1</sup>University of Washington Applied Physics Laboratory ([shumway@uw.edu](mailto:shumway@uw.edu)), <sup>2</sup>Washington University St. Louis, <sup>3</sup>Texas A&M University, <sup>4</sup>Stony Brook University, <sup>5</sup>Queensland University of Technology, <sup>6</sup>Lunar & Planetary Institute, <sup>7</sup>Jet Propulsion Laboratory - CalTech, <sup>8</sup>Space Science Institute, <sup>9</sup>Purdue University, <sup>10</sup>Portland State University, <sup>11</sup>University of the Basque Country.

**Introduction:** Mars' surface is blanketed with regolith, which has had a remarkably uniform basaltic composition at each site where it has been studied [1, 2]. Due to its ubiquity and geochemical consistency, investigations of regolith shed light on Mars' geologic history, ongoing surface processes, and the modern hydrological cycle. A robust characterization of regolith is also critical for preparing for future human exploration of Mars, as there are many potential health hazards (e.g., ultrafine particles, oxidizers, toxic species, carcinogens) and in situ resources (e.g., water, fuel, construction materials) associated with regolith.

NASA's Perseverance rover recently explored the rim of Jezero crater, providing an opportunity to compare regolith between the crater rim and interior (e.g., [3, 4]). Characterizing regolith across a broad geographic area reveals how its composition varies due to local environments and lithologies. Here, we present new measurements of regolith on the Jezero crater rim conducted by the Planetary Instrument for X-ray Lithochemistry (PIXL), an X-ray fluorescence (XRF) spectrometer on Perseverance's robotic arm [5].

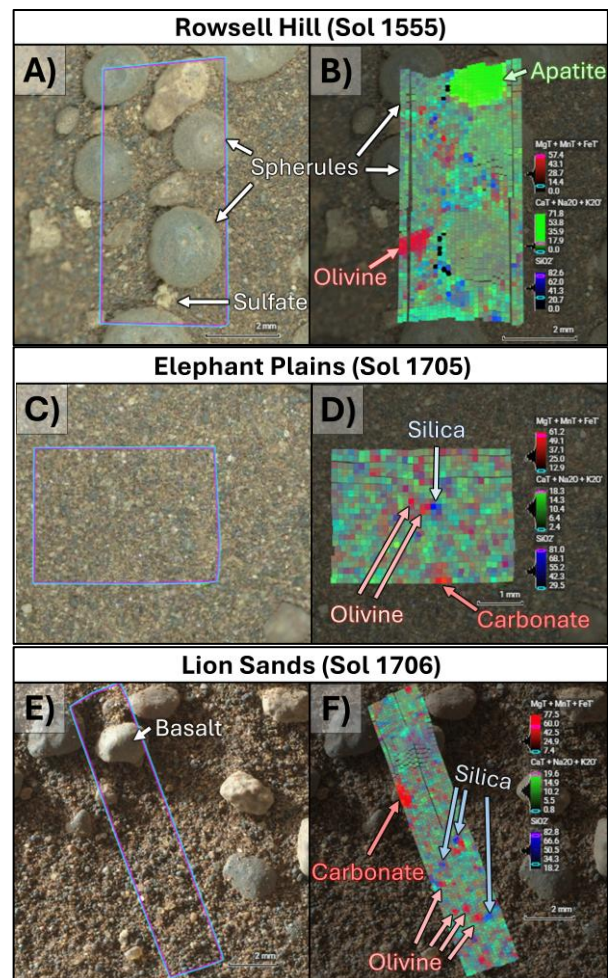
**Regolith Targets:** For simplicity, we refer here to grainsizes < 250  $\mu\text{m}$  (fine sand and smaller) as "fines" and grainsizes 0.5 - 4 mm (coarse sand to granules) as "coarse."

Inside Jezero, PIXL previously scanned regolith at *Observation Mountain*, an indurated megaregolith from which two regolith samples were cached for possible future return to Earth [4]. *Observation Mountain* consisted of fine (~125  $\mu\text{m}$ ) global soils and coarser grains (> 1 mm) interpreted to originate from local or regional sources, all coated with airfall dust [3].

On the crater rim, PIXL was deployed to study loose spherules concentrated in a patch of regolith overlying bedrock (target *Rowell Hill* on sol 1555). PIXL next probed regolith as part of a multi-instrument investigation of aeolian bedforms (additional results described in ref. [6]). At the *Hazyview* aeolian bedform, PIXL scanned the main armored surface (*Lion Sands*, sol 1706) in addition to superimposed, smaller (~10 cm crest-to-crest), fine-grained ripples (*Elephant Plains*, sol 1705).

**Regolith components:** *Rowell Hill* consisted of a bed of fines (i.e., < 250  $\mu\text{m}$ ) armored by a variety of

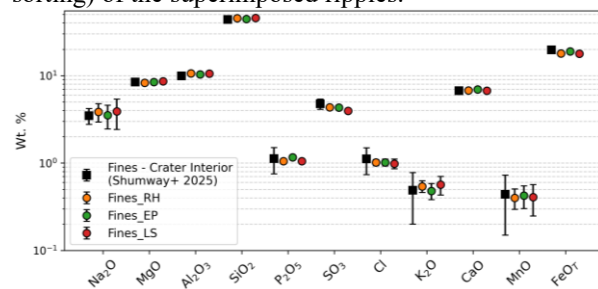
coarser grains (~0.5 - 3 mm): spherules, (chlor)apatite, olivine ( $\text{Fo}_{\sim 70}$ ), and sulfate ( $\text{Na}^+$  and/or  $\text{K}^+$  are plausible cations consistent with the data) (Fig. 1 A-B). The spherules were basaltic in composition and enriched in Ni relative to the surrounding material.



**Fig. 1** PIXL regolith targets on the crater rim imaged with WATSON (A, E) and the Auto-Context Imager (C). Color maps (B, D, F) visualize abundances (in wt. %) of  $\text{MgO}+\text{MnO}+\text{FeO}_T$  (red),  $\text{CaO}+\text{Na}_2\text{O}+\text{K}_2\text{O}$  (green), and  $\text{SiO}_2$  (blue). Color bars are uniform between panels for easy comparison; but note that some regions are oversaturated (e.g., "apatite" in B has up to ~75 wt.%  $\text{CaO}+\text{Na}_2\text{O}+\text{K}_2\text{O}$ , but the green color bar reaches maximum intensity at ~20 wt. %).

At *Elephant Plains*, only fines (i.e.,  $<250\ \mu\text{m}$ ) were scanned, though a few coarser grains are visible outside the XRF map area (Fig. 1 C-D). The *Lion Sands* scan also captured fines, plus two coarser grains: a basaltic rock fragment and an Fe-, Mg- carbonate (Mg#=60) (Fig. 1 E-F). Both *Elephant Plains* and *Lion Sands* fines contained vitreous yellow-green olivine grains (Fo<sub>-52</sub> and Fo<sub>-60</sub>, respectively). Each of the three targets also had fines with compositions trending towards a pure-silica endmember, possibly quartz.

Fines at each target also contained enrichments in chromium (quantified as Cr<sub>2</sub>O<sub>3</sub>), with *Elephant Plains* having the highest relative abundance of spots with Cr<sub>2</sub>O<sub>3</sub>  $> 1$  wt.%. Previous investigations identified similar Cr-enrichments in the Bagnold Dunes (Gale crater), possibly concentrated via transport and sorting [7]. Similar mechanisms could be concentrating Cr-rich grains in *Elephant Plains*, since context images captured by PIXL  $\sim 3$  hours apart show movement of several fines, suggesting active transport (and possible sorting) of the superimposed ripples.



**Fig. 2** Compositions of the finer-grained regolith fraction (i.e.,  $< 250\ \mu\text{m}$ ) inside Jezero crater (black squares, [3]), and at crater rim targets Rowsell Hill (RH; orange), Elephant Plains (EP; green), and Lion Sands (LS; red). Major oxide abundances are largely consistent between all targets, with only minor variations ( $< 10\%$ ), except for SO<sub>3</sub> ( $\sim 13\%$  difference).

**Regolith Composition:** Overall, the compositions of the fines at each crater rim target were consistent (within error) with each other and with the fines at *Observation Mountain* (Fig. 2, [3]). This result suggests the fines are geographically widespread and likely related to so-called “global soils” that have been encountered at sites across Mars [1, 2].

Crater rim fines contain an average of  $\sim 1$  wt. % Cl, with individual measurements up to  $\sim 4$  wt. % Cl. SO<sub>3</sub> and Cl abundances here are lower by  $\sim 13\%$  and  $\sim 9\%$ , respectively, relative to fines inside Jezero (Fig. 2). S and Cl can form soluble species, so variable concentrations could result from differing aqueous histories (e.g., Jezero crater once held a lake, unlike the crater rim) and/or may be due to a relative depletion in dust on the crater rim targets compared to *Observation Mountain* (as identified from high-resolution images).

**Relevance to Human Exploration of Mars:** The geochemical uniformity of fines between the crater interior and rim confirms that the two cached regolith samples (*Atmo Mountain* & *Crosswind Lake*) are representative of regolith over a wide geographic area (possibly global). These new data from relatively less dusty targets also confirm that airfall dust is present in the regolith samples, which is significant because studies of dust are highly prioritized due to the physical (e.g., ultrafine particle sizes) and chemical hazards (e.g., oxidizers, toxic species) posed to human explorers. The identification of olivine and carbonate in regolith is important because of their in situ resource utilization (ISRU) potential for construction materials and fuel production (e.g., Mg-cement and H<sub>2</sub>) [8].

Although PIXL cannot directly quantify oxygen, perchlorate (ClO<sub>4</sub>) is often inferred wherever Cl is detected on Mars [9]. If we infer the Cl measured here (up to 4 wt. %) includes ClO<sub>4</sub>, then it is likely that water vapor is being exchanged with the atmosphere to form hydrated salts or possibly (meta)stable liquid brine (i.e., via deliquescence) [10]. ClO<sub>4</sub> in regolith therefore has very high ISRU potential as a reservoir of H<sub>2</sub>O, and perhaps as a solid propellant oxidizer [11]. Perchlorates are also highly toxic to humans, so documenting their abundance and distribution is crucial for mitigating risks to future crewed missions.

The apparent concentration of Cr via aeolian processes is notable because the most oxidized state, Cr(VI), is a carcinogen. PIXL cannot discern the oxidation state of Cr, so future analyses (potentially of returned samples) are needed to assess this hazard.

Because of the numerous hazards posed by and resources contained within Martian regolith, extensive characterization—including the planned return of a sample of regolith and dust to Earth—is critical to enable human exploration of Mars. A comprehensive review of Perseverance’s contributions in support of future crewed missions is provided in ref. [12].

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**References:** [1] Clark B. C. et al. (1982) *JGR: Solid Earth*, 87, B12. [2] O’Connell-Cooper C. D. et al. (2017) *JGR: Planets*, 122, 12. [3] Shumway A. O. et al. (2025) *JGR: Planets*, 130, 10. [4] Hausrath E. M. et al. (2025) *JGR: Planets*, 130, 2. [5] Allwood A. C. et al. (2020) *Space. Sci. Rev.*, 216, 8. [6] Martin N. et al. (2025), *this meeting*. [7] O’Connell-Cooper C. D. et al. (2018) *GRL*, 45, 15. [8] Scott A. N. and Oze C. (2018) *Earth & Space Sci.*, 5, 8. [9] Clark B. C. and Kounaves S. P. (2016) *Int. J. Astrobiol.*, 15, 4. [10] Gough R. V. et al. (2011) *EPSL*, 312, 3. [11] Hoganson A. C. et al. (2024) *J. Propuls. Power*, 40, 3. [12] Connell S. A. et al. (2025), *this meeting*.