THE NATURE OF IGNEOUS OLIVINE CUMULATE ROCKS IN JEZERO CRATER, MARS. Y. Liu[1], A.C. Allwood[1], A.H. Treiman[2], M.E. Schmidt[3], P.D. Asimow[4], O. Beyssac[5], C.D.K. Herd[6], B.C. Clark[7], M. Wadhwa[8], A. Brown[9], T.V. Kizovski[3], J. Henneke[10], D.A.K. Pedersen[10], S.J. VanBommel[11], M.M. Tice[12], M.W.M. Jones[13], J.A. Hurowitz[14], J.D. Hernandez-Montenegro[4], A.L. Knight[11], S. Sharma[1]. [1]Jet Propulsion Laboratory, California Institute of Technology (Caltech), Pasadena, CA, USA. [2]Lunar & Planetary Institute (USRA), Houston TX 77058, USA. [3]Dept. Earth Sci., Brock Univ., St. Catharines, ON, Canada. [4]Div. Geosic. Planet. Sci., Caltech, Pasadena, CA, USA. 5 5IMPMC, Paris, France. [6]Dept Earth & Atm. Sci., University of Alberta, Edmonton, Alberta T6G 2E3, Canada. [7]Space Science Institute, Boulder, CO, USA. [8]School of Earth & Space Exploration, Arizona State Univ., Tempe, AZ, USA. [9] Plancius Research, MD 21146, USA. [10]Technical Univ. of Denmark, Kongens Lyngby, 2800, Denmark. [11]Dept. Earth Planetary Sci., Washington Univ., St. Louis, MO, USA. [12]Dept. Geology & Geophysics, Texas A&M Univ., College Station, TX, USA. [13]Central Analytical Research Facility, Queensland Univ. Technology, Brisbane, QLD, Australia. [14]Dept. Geosci., Stony Brook U., Stony Brook, NY, USA (yang.liu@jpl.nasa.gov).

Introduction: An olivine-rich unit on the western side of Jezero crater floor, named the Séítah formation, is potentially part of an extensive olivine-rich regional unit (circum-Isidus unit, >70,000 km^2) identified from orbital data (e.g., [1,2]). Before landing, hypotheses for the origin of this unit included impact melt [3], an igneous intrusive complex [4], basaltic flows [5,6], volcanic ash [2,3], and clastic material [7].

The first outcrop (Brac) studied with all instruments onboard the Perseverance rover revealed that the rock is an igneous olivine cumulate rock [8,9]. Such a finding excludes the Séítah formation being an ash deposit or of clastic origin [9]. During the crater floor campaign, the Perseverance rover abraded three rock outcrops (Bastide, Brac and Issole) in the Séítah formation (the patches, in turn, are named Garde on Bastide, Dourbes on Brac, and Quartier on Issole). PIXL collected only multispectral images of Garde but collected both multispectral images and XRF data on Dourbes and Quartier. The texture of Garde from the multispectral images is nearly identical to that of Dourbes. Here, we present an overview of the mineralogy and texture of Dourbes and Quartier, in order to gain further insights into the formation of this olivine-rich unit.

Results and discussion:

Dourbes. Based on the texture, grain orientation analyses and chemistry, Brac is an olivine cumulate rock that experienced moderate aqueous alteration [9,10]. The protolith of Brac consists mainly of coarse olivine grains ($Fo_{55\pm1}$, up to 3.5 mm, ~75 vol%) with interstitial augite ($Wo_{35-38}En_{43-44}Fs_{20-21}$, up to 8 mm, ~14 vol%) and mesostasis (alkali feldspar, plagioclase, Fe-Cr-Ti oxides, phosphate, ~11 vol%) (Fig. 1). Olivine grains are equant but rounded with melt inclusions (typically 100-300 µm). Olivine grains poikilitically enclosed in large augite display similar chemistry to those in the non-poikilitic regions. Bulk chemistry of the areas scanned by PIXL shows the rock is ultramafic with Mg# of ~55. The proportion of minerals suggests the protolith of Brac is an olivine-rich wehrlite. These Brac results indicate that the protolith likely formed through a multi-stage cooling history, involving initial relative fast cooling as indicated by large melt inclusions followed by relatively slow cooling to allow the accumulation of olivine and formation of large pyroxene grains, and homogenization of Fe/Mg in and between olivine and pyroxene. This finding is consistent with more than one emplacement mode, including a surface flow >100 m thick or a shallow subsurface sill of comparable thickness [9].

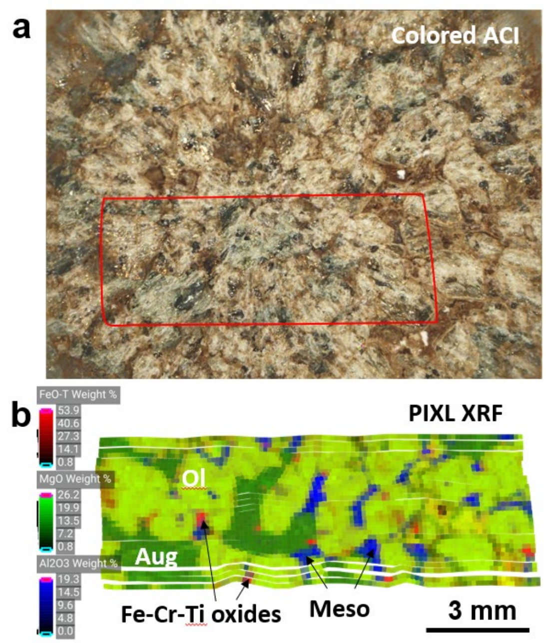

Fig. 1. Texture of Dourbes abraded patch. a) SHERLOC ACI image of part of the abraded patch. b) Composite map using Fe, Mg, and Al from PIXL XRF data of red outlined area shown in a). Ol: olivine. Aug: augite. Meso: mesostasis.

Quartier. The Quartier patch shows a similar cumulate texture as Dourbes, with abundant olivine and poikilitic textures (Fig. 2), as well as the effects of aqueous alteration that includes significant Mg and Ca sulfates. The major constituents of the pristine portion of the Quartier patch are olivine, augite, and feldspar. In the areas scanned by PIXL, orthopyroxene is a trace component. However, Quartier olivine displays different morphology than that in Dourbes. Olivine grains enclosed by augite display both chain habit and skeletal form (Fig. 3), both of which are indicators of rapid growth under a large degree of undercooling cooling and a rapid cooling. However, olivine grains in the non-poikilitic regions of Quartier are more tabular and prismatic than those in Dourbes (up to -8 mm [11]). Olivine in Quartier are more compositionally evolved than in Dourbes (~Fo_{45}). Melt inclusions (100-300 μm) are also present in Quartier olivine. Augite in Quartier is also slightly more Fe-rich than that in Dourbes ($Wo_{32-35}En_{39-40}Fs_{26-28}$). The feldspar in Quartier appears to be only alkali feldspar. The record of rapidly grown olivine enclosed by augite, the slowly grown olivine in non-poikilitic regions, and the overall more evolved olivine compositions suggests that Quartier/Issole is likely derived from a more fractionated melt than Dourbes/Brac and which experienced an initial large thermal change with rapid cooling followed with a slow cooling. A possible environment for such thermal changes can be rapid emplacement, magma convection, or magma mixing.

The olivine chemistry and sizes are consistent with those inferred from orbital observations for the regional unit (moderate Fo, 1-4 mm, [12, 13]). All three rocks analyzed by PIXL suggest the Séítah formation likely formed through fractionation of a large magma body that may have been built incrementally.

Other Séítah rocks. In addition to three abraded rocks in south Séítah investigated by all instruments, SuperCam performed point analyses and measured chemistry and mineralogy of 63 distinct targets from east, south, and northwest Séítah from Sol 173 to Sol 420 [14]. Results show that all Seitah rocks are expected to be igneous cumulates, displaying chemical and mineralogical variations consistent with igneous fractionation.

Implications. Formation through igneous fractionation and accumulation for Séítah implies that the regional extensive olivine-rich unit cannot be easily explained by any single mechanism. Whether the units outside Jezero crater are petrogenetically linked to the Séítah formation will be tested when Perseverance explores the marginal unit and the crater rim.

References: [1] Kremer, C. H., Mustard, J. F. and Bramble, M. S. (2019) *Geol., 47*, 677–681. [2] Mandon, L. et al. (2020). *Icarus, 336*, 113436. [3] Mustard, J. F. et al., 2009. JGR. 114. 2009JE003349. [4] Hoefen, T. M., et al. (2003). *Sci, 302*, 627–630. [5] Hamilton, V. E. and, Christensen, P. R. (2005) *Geol.*, *33*, 433–436. [6] Tornabene, L. L., et al. (2008) *JGR, 113,* 2007JE002988. [7] Rogers, A., et al. (2018) *GRL, 45,* 1767-1777. [8] Farley, K. A. et al. (2022) *Sci., 377*, eabo2196. [9] Liu, Y. et al. (2022) Sci., 377, 1513-1519. [10] Tice, M. et al. (2022) *Sci. Adv., 8,* eabp9084. [11] Hernandez-Montenegro, J.D. et al. (2023) this volume. [12] Brown, A. J., Viviano, C. E. and Goudge, T. A. (2020) *JGR, 125*, 2019JE006011. [13] Ody, A., et al. (2013) *JGR, 118,* 2012JE004149. [14] Beyssac, O., et al. (2023) *JGR,* submitted.

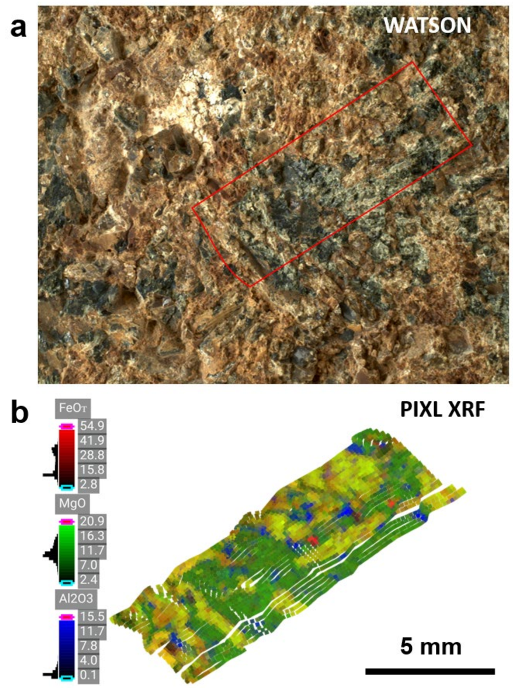

Fig. 2. Texture of Quartier abraded patch. a) WATSON image of part of the abraded patch. b) Composite map using Fe, Mg, and Al from PIXL XRF data of red outlined area shown in a). Ol: olivine. Aug: augite. Meso: mesostasis.

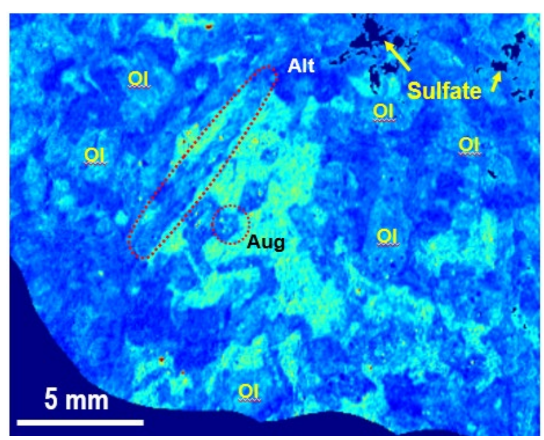

Fig. 3. PIXL MCC ratio image of Quartier. The noisy edge was removed. Dotted red lines enclose chained and skeletal olivine grains.