ORIGIN AND EMPLACEMENT OF THE CIRCUM-ISIDIS OLIVINE-RICH UNIT. C. H. Kremer[1*], J. F. Mustard[1], and M. S. Bramble[1], [1]Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912 ([*]christopher_kremer@brown.edu)

Introduction: The olivine-rich unit of the circum-Isidis region (Fig. 1) is one of the most geographically extensive and olivine-enriched ultramafic rock units exposed on the martian surface [1]. The unit also has a diverse suite of alteration minerals, with detections of serpentine, magnesite, smectite, and talc [2,3], making it attractive for *in situ* astrobiological and petrologic study. A variety of hypotheses have been suggested for the origin of the olivine-rich unit, including emplacement as 1) crustal intrusions [4], 2) picritic lava flows [5], and 3) ejected impact melt [1] or 4) a globally distributed condensate layer from the Isidis-forming impact [6] (Table 1). These hypotheses imply different emplacement timing, temperatures, and rock textures and therefore have different implications for the unit's significance as a record of potentially habitable subsurface environments in the region, as well as for the interpretation of olivine-rich rocks elsewhere on Mars.

We constrain the unit's depositional origin by mapping its total extent and by synthesizing new morphometric measurements of the unit with new and previous stratigraphic and textural observations. We present criteria to evaluate these hypotheses with *in situ* measurements from proposed exploration in the region by the Mars 2020 rover.

Characteristics: The olivine-rich unit is part of a succession of variably aqueously altered rocks in the Nili Fossae and Libya Montes regions, overlying phyllosilicate-enriched basement and underlying a mafic capping unit, as well as local outcrops of layered sulfates and Syrtis Major lavas [1,4,7–10]. The ~3.96 Ga Isidis-forming impact provides the upper bound on the olivine rich unit's age, and the opening of the Nili Fossae graben, which cross-cut the unit and are draped by the up to ~3.6 Ga Syrtis lavas, provide the lower bound [1]. The unit is generally characterized by polygonal fracturing [8], light tonality, and internal banding [1], as well as a spectroscopic signature consistent with olivine in modal abundance of up to 40% [11]. The unit is observed to drape the underlying basement unit, which exhibits topographic undualtions across many hundreds of meters of elevation [1,8].

Emplacement Mechanism: The early hypothesis that the olivine-rich unit was an exposed igneous intrusion has been discounted by the unit's inferred draping over the topography of the basement rock. More recent explanations invoking ultramafic melts face other difficulties, such as the absence of flow features or vents required for lava flows. Observations that the olivine-rich unit drapes topography are hard to reconcile with the low (~1-10 Pa s) viscosities implied by laboratory study of picrites [12] for hypothetical impact melts or lavas of such ultramafic compositions. Topographic draping and observations that the unit superposes the floor and rim of Jezero crater [9], which formed after Isidis, are also inconsistent with globally resurfacing rainfall invoked in models that argue for the origin of the olivine unit as an impact-generated condensate.

The unit's inferred topographic draping, proximity to the Syrtis Major volcano, and possible layering, as well as *in situ* evidence for distal ultramafic tephra on Mars [13], prompt quantitative investigation into its possible origins as an ash fall deposit.

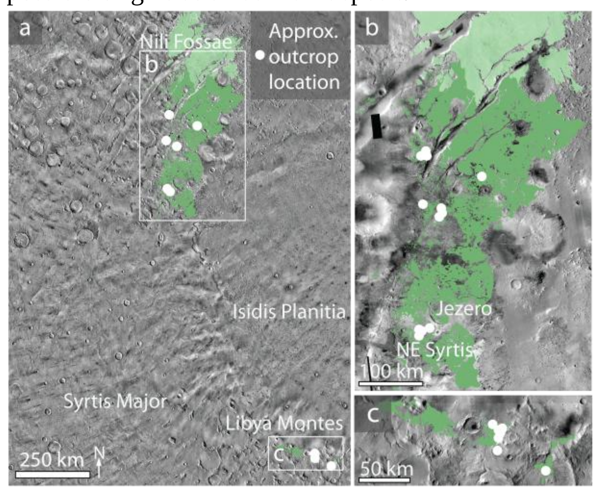

Fig. 1. *A) Distribution of the circum-Isidis olivine-rich unit (green) and possible extent (light green). B) Nili Fossae region. C) Libya Montes region. Adapted from [5,8,9].*

Methods: We mapped the total outcrop extent of the olivine-rich unit using geomorphic criteria described above with imagery from the High Resolution Imaging Science Experiment (HiRISE) [14] and imagery mosaics from the Context Camera (CTX) [15] and validated this geomorphic mapping using spectral summary parameters from the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) [16]. Mapping in the Jezero watershed [9], NE Syrtis [8], and Libya Montes [5] regions was adapted and modified from previous mapping efforts.

We used the NASA Ames Stereo pipeline [17–19] to create digital terrain models from HiRISE stereo pairs acquired over outcrops with one or both of the unit's stratigraphic contacts. We tested the observation that the olivine-rich unit drapes underlying topography by extracting elevations of points traced along the unit's contacts and internal banding and by assessing the conformability of the layering and unit contacts by inspection. The thicknesses of 47 outcrops (Fig. 1) were estimated by measuring the total elevation change between the topographically highest and lowest exposures of the unit, using only outcrops where either one or both unit contacts were visible. Since previous simulations of explosive eruptions on Mars have shown that Syrtis Major is the only large volcano close enough to Isidis to have produced ash fall deposits there, we also evaluate trends in unit thickness relative to distance from Nili Patera, a caldera at Syrtis Major and the modern edifice's approximate geographic center.

Results: In the ~10 outcrops of the olivine-rich unit with well-exposed banding and one or more unit contact, the dips of the banding are approximately parallel with each other and with their basal and top unit contacts. This holds for both the tabular banding common in Libya Montes and in the more recessive, geometrically exquisite banding common in Nili Fossae (Fig. 2). The parallelism between banding and contacts with the basement unit corroborates previous claims that the olivine-rich unit drapes the underlying topography.

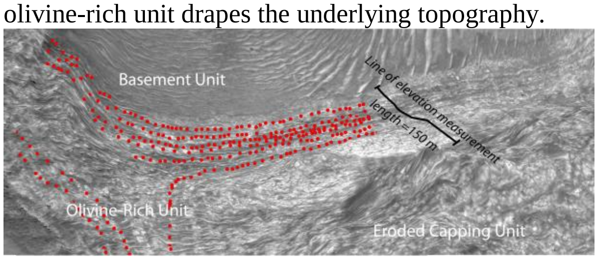

Fig. 2. *Parallel, topography-draping banding in olivine-rich unit partially traced by red dots. DEM from HiRISE images PSP_002888_2025 and PSP_002176_2025.*

Elevation changes in complete stratigraphic sections in Nili Fossae range from ~5 to ~25 m, and elevations associated with partial sections range from 12 to 60 m in Libya Montes, where the one complete section is 65 m thick. After excluding outcrops dipping parallel to modern topography, we find that the thickness of the olivine-rich unit inferred from outcrop elevation change in Nili Fossae decreases slightly from 16 m to 5 m with radial distance from Syrtis Major and that the olivine-rich unit in the one complete stratigraphic section in Libya Montes is significantly thicker than any outcrop in Nili Fossae (Fig. 3). No distinct trends are evident in unit thickness with respect to distance from the Isidis basin. Band thicknesses range from 0.38 to 2.0 m, with an average thickness of 1.0 m.

Discussion: The decrease in thickness of the olivine-rich unit away from Syrtis Major in Nili Fossae and the significantly greater thickness of the unit in Libya Montes are consistent with deposition of the unit as either picritic lava flows or as an olivine-rich ash sourced from Syrtis Major. A lava origin of the olivine-rich unit, however, is harder to reconcile with new data supporting observations that the olivine-rich unit drapes topography. In the absence of vents capable of feeding hypothetical picritic magma that would exist in the numerous exposures of the underlying basement unit, one might invoke ultramafic flood lavas, which would produce beds ranging up to 10s of m thick. This is difficult to reconcile with the thin, <1 m layering indicated by the banding, which in the case of an ash fall deposit would imply a volume within an order of magnitude of volumes of large terrestrial eruptions [20]. Martian ash fall deposits likely emplace near ~0 °C [13], suggesting against a contact metamorphism origin of aqueous minerals in the basement unit [3].

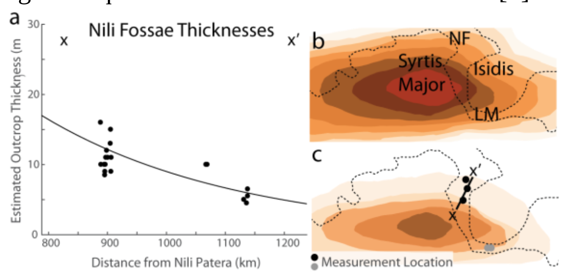

Fig. 3. *A) Olivine-rich unit thickness and distance from Nili Patera. B) Modeled pyroclast distribution for general eruption [21]. C) Schematic of potential ultramafic ash distribution from thickness measurements.*

Conclusions and Mars 2020: Our synthesis suggests that the circum-Isidis olivine-rich unit is likeliest to have emplaced as an ash fall deposit. Future *in situ* observations of gross bed and grain morphology by the Mars 2020 rover at NE Syrtis or Jezero crater would allow definitive identification of the origins of the deposit and its role in recording and facilitating potential subsurface habitats.

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