AN INTEGRATED SEDIMENTARY GEOLOGICAL SYSTEM AT NILI FOSSAE, MARS. C. H. Kremer[1], M. S. Bramble[1], and J. F. Mustard [1] Department of Earth, Environmental and Planetary Sciences, Brown University, Providence RI 02912 (christopher_kremer@brown.edu).

Introduction: Extensive *in situ* and orbital studies of martian sedimentary rocks have revealed that early Mars hosted diverse, potentially habitable surface environments [1,2]. Detailed studies that focus primarily on basinal sinks dominated by aqueous or aeolian activity leave much unknown about local- to global-scale routing of detritus from crustal sources to sedimentary sinks, relationships of globally distributed rock units with similar inferred mineralogy, and products of many potentially dominant sedimentary processes, including impact cratering and explosive volcanism.

The Nili Fossae region of Mars (Fig. 1), which has been extensively studied for its exceptionally diverse hydrous mineralogy and its potential ancient habitability [3–8], has previously recognized for its rich sedimentary record. Jezero crater (Fig. 1B), the landing site for the Mars 2020 rover [9], hosts well-preserved, ancient lacustrine deltas [10,11] whose watersheds extended over 30,700 km^2 of the Nili Fossae region [5]. Recent studies have suggested that texturally and mineralogically diverse clastic rock deposits comprise much of the Nili Fossae stratigraphy (Figs. 2-3) [12–14], whose ages span the critical Noachian-Hesperian environmental transition in early Mars history [3].

The absence of a common interpretive framework for the Nili Fossae stratigraphy limits attempts to place regional processes of crustal reworking into a global context. We propose a new synthesis that the Nili Fossae region hosts an ancient, integrated sedimentary system (Fig. 1A-B) that may serve as a mineralogical and lithologic reference stratigraphy for Mars in future orbital, *in situ*, and return sample science.

Geological Context: Orbital visible and near-infrared spectra reveal extensive alteration in the phyllosilicate-bearing regional basement (Figs. 2-3) [15]. An overlying stratigraphy locally up to hundreds of meters thick (Figs. 2-3) [3,6] includes an olivine-rich rock unit [13] that has been variably altered to Mg-carbonate, serpentine, and talc/saponite [3]; an olivine-poor mafic unit; a sulfate-bearing sedimentary formation [12]; and local layered basinal deposits [12]. Subsequent to deposition and alteration of these units, lavas locally resurfaced the region in the Hesperian (3.0–3.7 Ga) [16]. The most complete exposures of the Nili Fossae stratigraphy occur in the NE Syrtis Major region adjacent to Jezero crater (Figs. 1B, 2A).

Synthesis: *Clastic Basement*. Large impacts on early Mars, such as Borealis and Hellas, produced global equivalent layers of hundreds of meters of debris [17]. In the Nili Fosase region the Isidis basing-forming impact fractured, melted, and redistributed pre-existing crust in Nili Fossae, including ejecta from other basin-forming impacts.

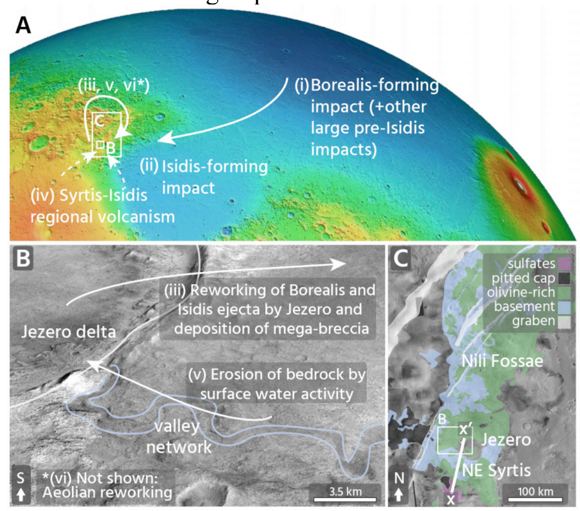

Figure 1. *(A) Multi-generational crustal recycling (numerals) in the Nili Fossae region. (B Detail) Integrated sedimentary system at Jezero-NE Syrtis. (C) Geomorphic map of exposed sedimentary lithologies in Nili Fossae after [5,6,13], with cross-section line in Fig. 3.*

While the origin of the >3.98 Ga, generally massive basement unit at Nili Fossae (Fig. 3B) remains an active area of investigation [14], its many exposures of megabreccia of varied tonal, spectral, and textural properties are suggestive of diverse provenance [18]. These blocks, which are up to hundreds of meters in diameter, likely incorporate materials that record denudation, transport, and re-deposition related to the widely- and deeply-sourcing large impacts on early Mars. Meter-scale internal layering within some breccia blocks indicate that prior sedimentary units have been recycled by impacts and other processes [18].

Airfall Facies. A basement-superposing olivine-rich unit has been recently interpreted as deposits of air-fall pyroclasts [13,19]. A pitted mafic cap unit overlies this olivine-rich unit preserved in hundreds of small mesas (Fig. 3C) and has been recognized as a probable ash-fall deposit based on its topographic draping [6] and spectrally inferred grain size and glass content [20,21]. The Jezero watershed region is thus a key region for studying explosive volcanism, a potentially dominant volcanic process on early Mars [22].

Water-lain sediments. The youngest major sedimentary unit in this stratigraphy is a 100s of meters

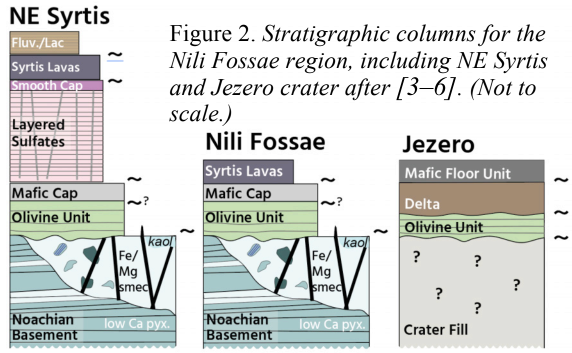

Figure 2. *Stratigraphic columns for the Nili Fossae region, including NE Syrtis and Jezero crater after [3–6]. (Not to scale.)*

thick layered sulfate unit observed in NE Syrtis (Fig. 2A) [12]. Younger water-lain sediments with variable textures, also in NE Syrtis, have recently been identified [12] and await further study.

Terminal Sink at Jezero. The Jezero delta deposits are the terminal sinks of watersheds [5] that dissected previously recycled clastic material in the Nili Fossae stratigraphy. Impact models imply that the Jezero-forming impact ejected a substantial amount of debris into the NE Syrtis area, although it is unclear whether any ejecta remains there [23]. The watershed region within ~20 km of Jezero would have acted as a sink for material that was excavated by Jezero from several kilometers depth and subsequently remobilized into the Jezero deltas, implying a locally integrated, two-generation history of recycling (Fig. 1B). We hypothesize that sediments in the Jezero delta may therefore be among the most physically and geochemically mature sediments on Mars with discernible sedimentary source terranes.

Implications: With its diversity of lithology and process, areally extensive integration, and preserved source-to-sink relationships, the Nili Fossae stratigraphy contrasts with sedimentary sinks highlighted in previous work [2]. Many of the diverse textures, mineralogies, and depositional processes of the Nili Fossae stratigraphy have potential analogs or correlative units elsewhere on the planet, making it a valuable reference stratigraphic section for constraining relationships between inferred physical sedimentary and mineralogical-geochemical environments on early Mars. Nili Fossae's multi-generational record of clastic recycling also makes it a key region for understanding the prolonged maturation of sediments during a critical period of global environmental transition.

Integrated *in situ* investigation of Jezero crater and the neighboring crater rim and watershed will allow for detailed source-to-sink geological analysis of a martian sedimentological system, providing vital geological context for measurements at Jezero.

References: [1] Malin M. C. and Edgett, K. S. (2000) *Science*, *290*, 1927–1937. [2] Grotzinger J. P. and Milliken, R. E, *Sedimentary Geology of Mars*, SEPM (2012), pp. 1–48. [3] Ehlmann B. L. and Mustard, J. F. (2012) *GRL*, *39*, L11202. [4] Mangold N. et al. (2007) *JGR*, *112*. [5] Goudge T. A. et al. (2015) *JGR Planets*, *120*, 775–808. [6] Bramble M. S. et al. (2017) *Icarus*, *293*, 66–93. [7] Salvatore M. R. et al. (2018) *Icarus*, *301*, 76–96. [8] Amador E. S. and Bandfield, J. L. (2016) *Icarus*, *276*, 39–51. [9] Grant J. A. et al. (2018) *PSS*, *164*, 106–126. [10] Goudge T. A. et al. (2017) *EPSL*, *458*, 357–365. [11] Fassett C. I. and Head, J. W. (2005) *GRL*, *32*.[12] Quinn D. P. and Ehlmann B. L. (2019) *JGR Planets,* In Press. [13] Kremer C. H. et al. (2019) *Geology,* In Press. [14] Scheller E. L. and Ehlmann B. L. (2019) *LPS XLIX*, Abstract #2033. [15] Ehlmann B. L. et al. (2009) *JGR*, *114*. [16] Hiesinger H. and Head, J. W. (2004) *JGR*, *109*. [17] Nimmo F. et al. (2008) *Nature*, *453*, 1220–1223. [18] Mustard J. F. et al. (2009) *J. Geophys. Res.*, *114*, E00D12. [19] Rogers A. D. et al. (2018) *GRL*, *45*, 1767–1777. [20] Edwards C. S. and Ehlmann, B. L. (2015) *Geology*, *43*, 863–866. [21] Cannon K. M. et al. (2017) *JGR Planets*, *122*, 249–268. [22] Bandfield J. L. et al. (2013) *Icarus*, *222*, 188–199. [23] Bramble et al. (2018) *LPS XLIX*, Abstract #1705.

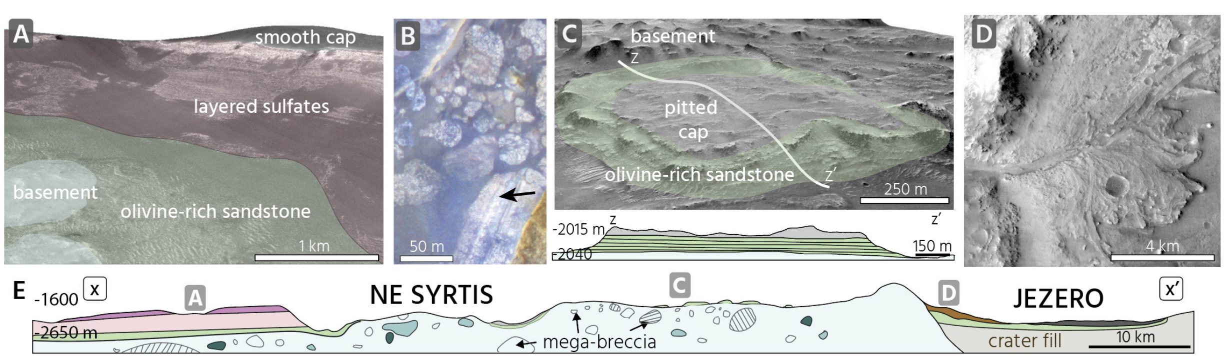

Figure. 3. *(A) Stratigraphy in Fig. 2A (HiRISE ESP_042671_1970 stereopair). (B) Layered (arrow) basement megabreccia (ESP_033572_1995). (C) Mesa of interpreted air-fall deposits (ESP_015942_1980 stereopair). (D) Jezero delta. (E) Interpreted cross section of the NE Syrtis-Jezero area after [3,5,12] with units from Fig. 2 and location in Fig. 1C.*