MEGABRECCIA AT NORTHEAST SYRTIS MAJOR AND ITS IMPORTANCE FOR MARS SCIENCE. B. P. Weiss[1], E. Scheller[2], Z. Gallegos[3], B. L. Ehlmann[2], N. Lanza[4], and H. E. Newsom[3], [1]Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA, USA (bpweiss@mit.edu), [2]Division of Geological and Planetary Sciences, Massachusetts Institute of Technology, Pasadena, CA, USA, [3]Institute of Meteoritics, University of New Mexico, Albuquerque, NM, [4]Los Alamos National Laboratory, Los Alamos, NM

Introduction: Megabreccia is a cataclastic deposit of large (here defined as ≥10 m diameter), typically angular blocks set within a finer-grained matrix. Megabreccia is a high priority target for in situ Mars exploration and sample return because it is likely some of the oldest exposed materials on Mars and may contain unique records of early Martian geologic history. Here we address three questions about the megabreccia:

1. What is the significance of Martian megabreccia?
2. What is the nature of the megabreccia within the proposed northeast (NE) Syrtis Mars 2020 landing site ellipse?
3. What are the origin and age of the megabreccia?

We assessed these questions by investigating the size and shape, texture, mineralogy, spatial distribution, and stratigraphic position of the megabreccia blocks within and around the landing ellipse in context with the geology of NE Syrtis and studies of terrestrial impact craters.

Origin and Significance: Megabreccia has been identified on Earth [1] and Mars [3-7]. On Earth, it formes in highly energetic environments such as meteoroid impacts [8], volcanic events [9] and landslides [10]. On Mars, megabreccia has been imaged in central peaks of large Noachian craters and on the rims of basins in Noachian terrains. The strong association of megabreccia with impact craters and the modest nature of global-scale tectonic activity on Mars [11] most Martian megabreccia have an impact origin.

Martian megabreccia may provide the earliest records of Martian paleoclimate and habitability including aqueous processes, biosignatures, planetary accretion, and igneous differentiation. Because many megablocks are layered and may have been derived from locations in the original bedrock close to those of adjacent blocks, they could provide access to up to hundreds of meters of intact stratigraphy of the ancient crust. Additionally, because the Martian dynamo is thought to have ceased prior to the beginning of the early Noachian, megabreccia may also provide the only accessible materials that could constrain the ancient Martian dynamo, whose demise may have been a key factor in the loss of an early thick atmosphere [12, 13].

Megabreccia at NE Syris: Numerous megabreccia exposures are found in an arc along the western rim segment of Middle-Early Nochian Isidis impact basin [3, 4 14, 15] in a region thought to be located between the inner and outer rings of the impact structure [16]. As described by ref. [4], we mapped 147 megabreccia outcrops in this region, focusing in particular on the candidate Mars 2020 landing site ellipse. We observed a variety of textures, albedos and colors, with some blocks exhibiting clear banding. Mapping of stratigraphic relationships revealed that megabreccia blocks likely are samples of the pre-Isidis Noachian basement.

In the candidate NE Syrtis landing ellipse, there are 8 observed exposures of megabreccia containing a total of 53 blocks with diameters >10 m (Fig. 1). These blocks are sparser and/or less well-exposed compared to those in areas outside the ellipse and none exhibit banding. Four contain Fe/Mg-smectite while the other two contain low Ca pyroxene (LCP) and Fe/Mg-smectite (Fig. 1). Five contain both Fe/Mg-smectite and LCP-Fe/Mg-smectite mixtures. We did not observe any blocks of pure LCP composition, suggesting that all blocks are altered to some extent.

Terrestrial analogs:

Field studies and numerical modeling. Field studies show that the majority of megablocks produced by small complex craters (e.g., ~25 km diameter Ries crater) can be in the form of ejecta [17], while megabreccia formed by basin-scale events (e.g., the ~180-km diameter Chicxulub crater) is derived primarily from in situ disrupted basement and material flowing out from the initial central uplift [18]. Numerical modeling of the lunar Orientale basin (~900 km diameter) [19] shows the same wave-like structure of deeply sourced megabreccia flows. This material, now near the surface, may have originated from a depth of >50 km and experienced peak shock pressures of ~100 GPa.

On Mars, material sourced from the central region of Isidis was likely once present in the area of the current NE Syrtis landing ellipse; however, subsequent erosion of the basement unit (i.e., [3]) has probably removed much of the surface-flow megabreccia deposits and removed most of the continuous ejecta blanket in the area of the large exposed blocks. The deposits visible in the landing ellipse likely represent in-situ disrupted basement megabreccia derived from as much as 0-5 km deep and subject to pressures ranging from 0 up to >25 GPa. Therefore, this unit may contain relatively unshocked material from within the upper crust.

Crater scaling laws. Although the ellipse location within the inner ring of the Isidis basin strongly favors an origin of the megabreccia by a flux of materials from depth due to the Isidis impact, it is conceivable that some blocks could instead be ejecta from much younger

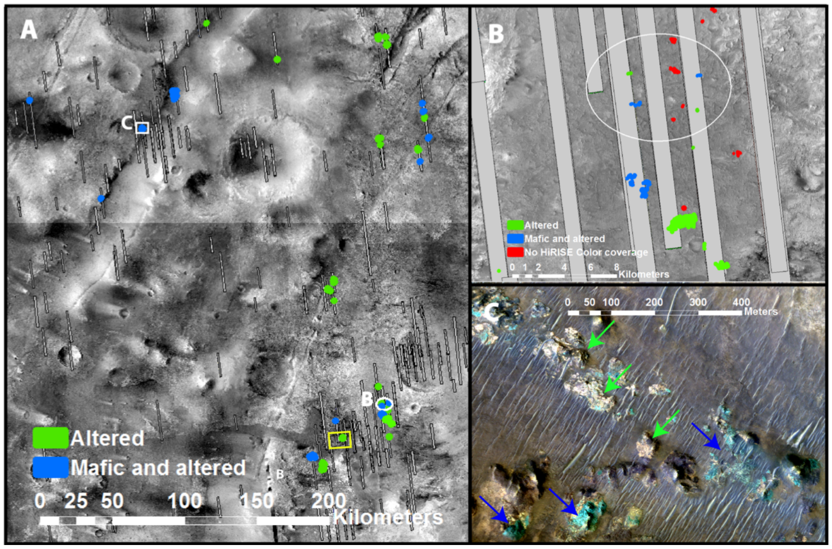

Fig. 1. Megabreccia at NE Syrtis, Mars. (A) Megabreccia compositions (on CTX background). By evaluation through HiRISE color, blue circles = megabreccia containing both LCP and phyllosilicates and green circles = megabreccia containing only phyllosilicates. Ellipse = candidate Mars 2020 landing site (B), white square = location of image in (C), and yellow square = proposed alternative landing site area. (B) Megabreccia block lithologies in and around the candidate landing ellipse. (C) Megabreccia exposure from ref. [3] in HiRISE color. Arrows show locations of blocks of mafic composition (blue) and Fe/Mg-smectites (green).

nearby craters like Jezero (49 km diameter) and Hargraves (65 km diameter). In particular, scaling laws show that for craters in the gravity regime, the continuous ejecta blanket typically extends ~2.35 crater radii from a crater's center [20]. This criterion excludes Hargraves but permits Jezero to be a significant source of ejecta at the NE Syrtis ellipse.

We assessed the expected number of Jezero ejecta blocks in the megabreccia range using gravity-regime crater scaling laws [21, 22]. We find that Jezero should have produced blocks with diameters up to ~500 m. However, given the expected ejecta size distribution and the size of Jezeros' ejecta blanket compared to the size of the landing ellipse, we estimate that <1 ejecta blocks of diameter >10 m should be present in the ellipse.

Findings: We have four main findings:

1. Most NE Syrtis megabreccia is likely from the Isidis impact event. The evidence for this is that:

- the ellipse is located between the inner and outer rings of Isidis, where megabreccia should form.
- the megabreccia is almost exclusively confined to the Basement Unit of ref. [14].

2. NE Syrtis megabreccia may retain records of the Mid-Noachian, and possibly even pre-Noachian geologic, climatic, astrobiological and magnetic history of Mars. This is supported by the fact that:

- the Isidis impact is thought to have occurred in the early Late-Early Noachian.
- the megabreccia are expected to include significant quantities of materials not shocked to above 5 GPa.
- blocks located outside of the landing ellipse contain layering that may be Noachian stratigraphy.

3. The nature of the megabreccia's geologic record is currently uncertain. This is due to the following:

- The blocks' small sizes makes it difficult to establish from orbit whether they are are igneous or sedimentary and the extent of any metamorphism and shock.

4. Because the best megabreccia exposures are outside the current landing ellipse, we propose an alternative landing location and extended mission targets for further study. Unlike the current ellipse, the new area is

- of interest because it contains well-expressed exposures of layered blocks.
- closer to the sulfate unit and Syrtis Major lavas.

References: [1] S. Vishnevsky and A. Montanari (1999) *Geol. Soc. Am. Spec. Pap., 339*, 19-59. [2] J. A. Grant et al. (2008) *Geology, 36,* 195-198. [3] J. F. Mustard et al. (2009) *JGR*, *114*, E00D12. [4] E. Scheller and B. L. Ehlmann, *LPS XLIX*, submitted. [5] J. L. Murchie et al. (2009) *JGR, 114,* E00D06. [6] L. L. Tornabene et al. (2008) *JGR, 118,* 994-1012. [7] A. S. McEwen et al. 2009, *EPSC, 4,* 2009-504-2. [8] D. J. Roddy et al. (1977) *Impact and Explosion Cratering* (Pergamon Press, New York). [9] D. R. Shawe and D. B. Snyder (1988) *USGS Spec. Pap. 1471.* [10] M. H. Krieger (1977) *USGS Prof. Pap. 1008*. [11] S. M. McClennan (2011) in *Sedimentary Geology of Mars* (eds. J. P. Grotzinger and and R. E. Milliken), pp. 119-138. [12] M. H. Acuña et al. (2008) in *The Martian Surface: Composition, Mineralogy, and Physical Properties* (ed. J. F. Bell) pp. 242-262. [13] B. P. Weiss et al. (2008) *GRL, 35,* L23207. [14] M. S. Bramble et al. (2017) *Icarus, 293,* 66-93. [15] T. A. Goudge et al. (2015) *JGR, 120,* doi:10.1002/ 2014JE004782. [16] J. F. Mustard et al. (2007) *JGR, 112,* doi:10.1029/ 2006JE002834. [17] S. Sturm et al. (2015) *MPS, 48,* 515-589. [18] G. S. Collins et al. (2017) *LSC XLVIII,* abstract #1832. [19] B. C. Johnson et al. (2016) *Science, 354,* 441-444. [20] H. J. Melosh (1989) *Impact Cratering: A Geologic Process* (Oxford University Press). [21] K. R. Housen and K. A. Holsapple (2011) *Icarus, 211,* 856-875. [22] R. N. Clark et al. (1993) *USGS Open File Rept. 93-592.*