GEOLOGIC MAPPING AS A GUIDE TO ROVER MISSION PLANNING ON MARS.
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Introduction: Geologic maps depict the location, nature, spatial relationship, and age of rocks and other geologic features exposed on a surface (e.g., **Fig. 1**). On Mars, geologic maps produced from orbital data are used to evaluate candidate sites for future landed missions. Once a rover is on the ground, these maps, derived from high resolution orbital data, help guide the rovers to prime science targets that enable mission objectives to be achieved. The iteration between predictions made from orbit and *in situ* measurements help refine rover-based interpretations and place discoveries from the surface in a broader geologic framework.

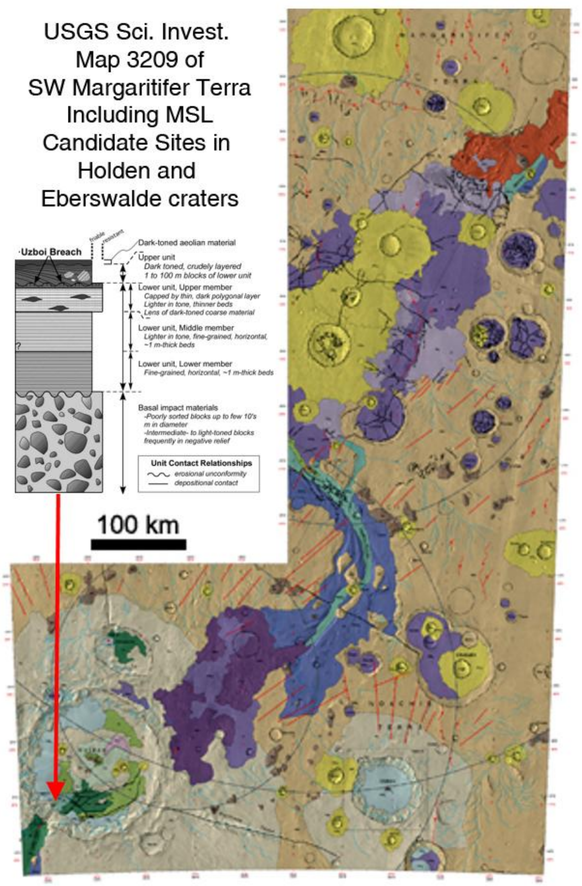

Fig. 1. Orbital mapping [1, 7] of a candidate landing site in Holden crater establishes the distribution of high priority science targets (inset, see Fig. 3 in [7]) and terrain hazards. Map of MTM quadrangles –15027, –20027, –25027, and –25032, see [1] for explanation.

Geologic Mapping Prior to Landing: Maps supporting the selection of landing sites are produced at a variety of scales using spectral (TES, THEMIS, OMEGA, CRISM) and image (THEMIS VIS, HRSC, MOC, CTX, HiRISE) datasets with a range of resolutions. These maps are sometimes published as formal USGS products (e.g., **Fig. 1** [1]) and include both geomorphic (landform) and geologic (stratigraphy) products. Many geologic maps are presented at landing site workshops and are used as a tool for assessing the nature, distribution, age, interpretation, and accessibility of high priority science regions of interest (ROIs), and possible hazards at a site.

For the Mars Science Laboratory *Curiosity*, detailed maps were produced for many of the proposed landing sites, including the four finalists in craters Holden, Eberswalde, Gale and the surface west of Mawrth Vallis. For example, mapping in Holden crater (**Fig. 1**) defines a series of clay-bearing aqueous deposits likely associated with a prolonged occurrence(s) of lacustrine and alluvial environments [1, 7]. At Eberswalde crater, mapping describes relationships between 10 stratigraphic units that include a fan-shaped deposit on the western edge of the crater interpreted to be a lacustrine delta [2, 3]. For the landing site in Gale crater, mapping highlighted the clay-bearing under sulfate bearing layers forming Aeolis Mons and enabled characterization of the Peace Vallis alluvial fan and associated units [4, 6]. At Mawrth Vallis, data help characterize the geometry and the composition of an ancient and broadly distributed clay-rich unit [8, 9].

Geologic Mapping at Gale Crater After Landing: Selection of Gale crater as the landing site for *Curiosity* led to additional mapping (**Fig. 2**) at 1:10,000 (based on quadrangles covering 0.025°). Mapping at this scale provides knowledge of the distribution of science targets and the geologic context necessary to place observations and interpretations made at the rover scale into a broader context [10-12]. Related terrain mapping focuses on defining and characterizing terrains that maximize the safety of the rover along its traverse to high priority science targets [14-16].

The map detailing the geology of the Gale landing ellipse continues to be refined based on results of *in situ* exploration by the rover [13] and delineates six major science units (**Fig. 2**). Definition of these units, together with terrain maps, was pivotal in guiding the *Curiosity* to Glenelg near Yellowknife Bay (YKB) at the junction of three units . The interpretation of alluvial and lacustrine units explored by the rover along the traverse to YKB were placed in broader stratigraphic context using the orbital map (**Fig. 2**) and enabled the age and extent of past habitable environments to be better constrained [17, 18]. Mapping using both orbital and surface-based data continues to guide *Curiosity* towards future exploration goals while enabling broader interpretation of discoveries made along the rover traverse.

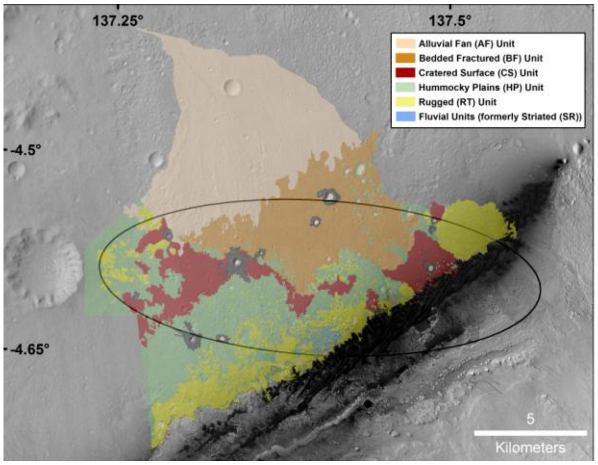

Fig. 2. Map of *Curiosity's* landing ellipse and surroundings in Gale crater. Version is updated from pre-landing original map and that shown in [17] when Curiosity was at YKB. See [17] for further details.

Geologic Mapping at Meridiani Planum: The Mars Exploration Rover *Opportunity* also makes use of both orbital and *in situ* mapping to define and characterize science targets and rover traverses. Orbital mapping using HiRISE, CTX, and CRISM data has guided the rover on a safe path across the Meridiani plains to Endeavour crater [e.g., 14] and identified important science targets along the way.

Orbital mapping also serves as a guide for *in situ* rover exploration at Capes York and Tribulation along the western rim of Endeavour that resulted in definition of stratigraphy including pre-impact country rock and ejecta deposits associated with formation of the crater [19, 20]. Mapping along the rover's traverse produces a "strip map" [21] that defines the geology from outcrop-to-outcrop and serves to ground truth features and variations in surface properties that are observed in orbital data sets of the same locations. Moreover, orbital mapping using CRISM data has pinpointed occurrences of smectite clays along the rim of Endeavour [22]. *Opportunity* is exploring the nature of these smectites in Marathon Valley (**Fig. 3**) and results should yield insight into past environmental conditions on Mars and help to calibrate orbital data for smectite detections elsewhere on the planet.

Summary: Geologic mapping of Mars using both orbital and surface-based data sets enables robust interpretation of stratigraphy and surface evolution and is a critical mission planning tool for guiding rovers safely to high priority science targets. Mapping employs an iterative approach where units and interpretations are updated as surface units and features are characterized and interpreted. Resultant maps are an important tool for placing rover results in a broader context and can facilitate interpretation of orbital data in locations where *in situ* exploration is not possible. The result is streamlined mission operations leading to robust interpretations of the geologic evolution of Mars [e.g., 23].

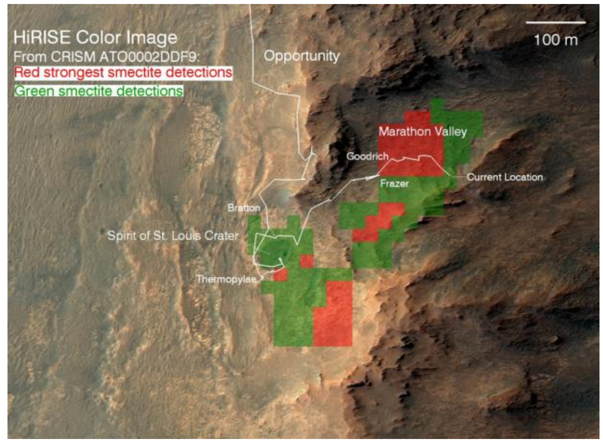

Fig. 3. Map of smectite clays detected by CRISM in Marathon Valley on the rim of Endeavour crater. Maps were generated using updated regularization technique of the CRISM ATO developed by Ray Arvidson and data are regularized to 12 m/pixel. Figure provided by Valerie Fox and Ray Arvidson (see [22] for details).

References: Irwin, R. P., III, and J. A. Grant (2013), *USGS Sci. Invest. Map 3209*. [2] Malin, M.C. and Edgett, K.S. (2003), *Science* 302, 1931–1934. [3] Rice, M. S., et al. (2013), *MARS*, 8, 15-57. [4] Anderson, R. B. and Bell, J. F., III (2010), *MARS*, 5, 76-128. [5] Milliken, R. E., et al. (2010), *GRL*, 37, L04201. [6] Thomson, B. J., et al. (2011), *Icarus*, 214, 413–432. [7] Grant, J. A., et al. (2008), *Geology*, 36, 195-198. [8] Loizeau, D., et al. (2009), *Icarus*, 205, 396. [9] Michalski, J. R. et al. (2020), *Astrobiology*, 10, 687-703. [10] Sumner, D. Y., et al. (2012), *Geol. Soc. Am. Abs. with Prog.*, Abstract 208852. [11] Calef, F. J., III, et al. (2013), *LPS XXXIV*, Abstract 2511. [12] Sumner, D. Y., et al. (2013), *LPS XXXIV*, Abstract 1699. [13] Rice, M. S., et al. (2013), *LPS XXXIV*, Abstract 2892. [14] Parker, T. J., et al. (2012), *LPS XXXIII*, Abstract 2535. [15] Parker, T. J., et al. (2013), *LPS XXXIV*, Abstract 2534. [16] Yingst, R. A., et al. (2014), *Geol. Soc. Am. Abs. with Prog.*, Abstract 202-8. [17] Grotzinger, J. P., et al. (2014), *Science*, 342. [18] Grotzinger, J. P., et al. (2014), *Science*, 350, 177. [19] Squyres, S. W., et al. (2012), *Science*, 336, 570-576. [20] Arvidson, R. E., et al. (2014), *Science*, 343. [21] Crumpler, L. S., et al. (2014), *JGR*, 120, 538-569. [22] Arvidson, R. E., et al. (2015), *AGU Fall Mtg.*, Abstract 2151. [23] Grant, J. A., et al. (2015), *Icarus*, in press.