THE SCIENTIFIC NECESSITY OF LANDING AT DIVERSE SITES ON MARS. J. J. Wray[1], [1]Earth & Atmospheric Sciences, Georgia Institute of Technology, 311 Ferst Drive, Atlanta, GA 30332 (jwray@gatech.edu).

On the surface of Mars, the mineralogic products of aqueous alteration eluded definitive detection for many years. Fluvial geomorphologies imaged by Mariner 9 and Viking strongly suggested past liquid water at the surface, but orbital infrared (IR) spectrometers on Mars Global Surveyor and other missions initially identified only unweathered primary minerals along with a few regional concentrations of hematite [1,2], the origin of which was ambiguous from orbit. Secondary minerals were found in meteorites ejected from unknown locations [3], but sample return was envisioned as the only way to get definitive answers about the aqueous history of dust-covered Mars.

Everything has changed in the past decade. The orbiting IR spectrometers OMEGA, THEMIS, and CRISM have revolutionized our view of the Martian surface by finding deposits of sulfates, phyllosilicates, and chloride salts ranging from the Martian equator to the poles [4-6]. Aqueous environments were not only present in the past, but were geochemically diverse, and may still be present in certain locations and at certain seasons/times of day in the modern era [e.g., 7].

The history of water on Mars is intimately related to all four MEPAG goals: searching for life, understanding climate history and planetary evolution, and preparing for exploration by humans (for whom water is a critical resource). Furthermore, four of the five "high priority" goals of Mars sample return relate to life, habitability, and the availability of water to form the rocks preserved at the surface today [8]. A full sample return campaign will cost $8-10 billion [9], equivalent to NASA's entire FY2012 budget for the Planetary Science Division over more than half a decade. If we go forward with sample return, it is imperative that we identify samples that will be most informative about the history of life, habitability and climate.

Have we yet identified such samples? Based on orbital data alone, we are faced with an embarrassment of *possible* riches. Fig. 1a shows layered rocks in the Mawrth Vallis region of Mars, composed of up to 65% clays or other secondary minerals, indicating extensive alteration by water [10]. These rocks have been variably interpreted as marine shales [11], impact ejecta altered under wet or dry conditions [12], fluvial or eolian deposits of transported clays [13], altered volcanic ash [14], and/or paleosoils [15]. Each interpretation has dramatically different implications for habitability and potential preservation of biosignatures, but none can be entirely excluded on the basis of orbital data alone.

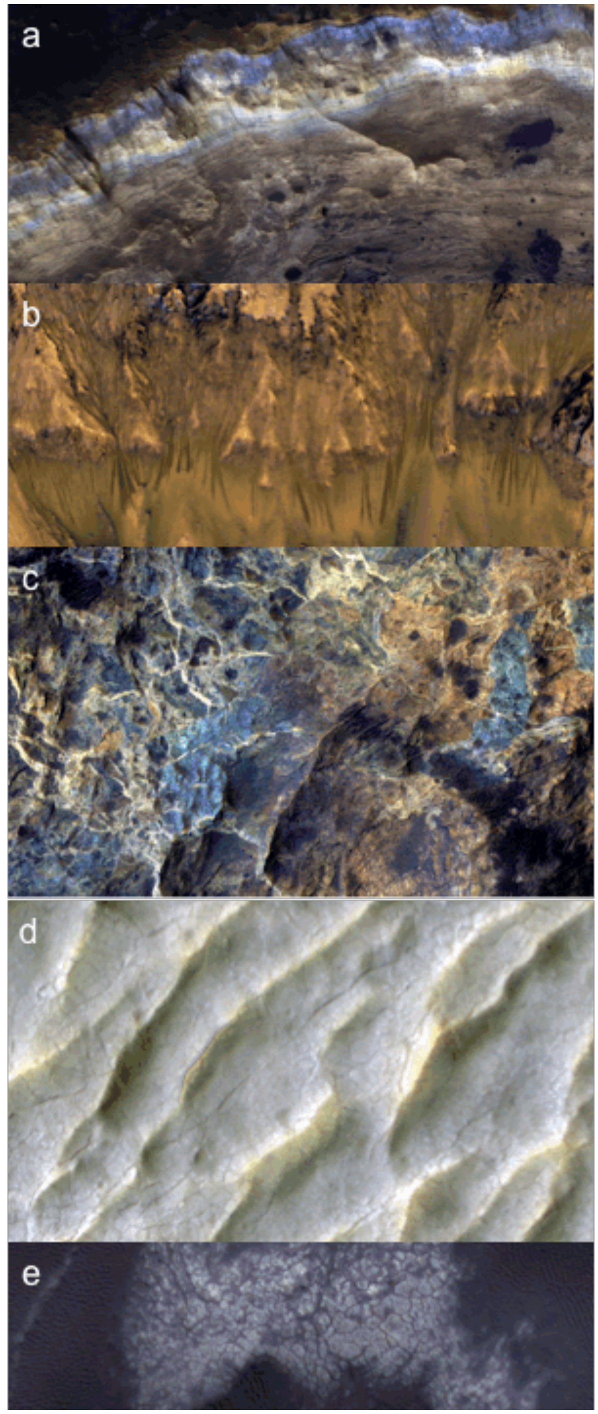

Figure 1. (a) Layered clays near Mawrth Vallis. (b) RSL in Newton basin. (c) Megabreccia in Holden crater. (d) Chlorides in Terra Sirenum. (e) Gypsum-rich dunes (dark) and polygonally cracked interdune deposits in Olympia Undae. All images from HiRISE.

Similar geologic uncertainty applies to each of the other fascinating images in Fig. 1. The dark streaks in Fig. 1b are recurring slope lineae (RSL) that form on sun-facing slopes during summertime and vanish each winter; these have been interpreted as active brine flows, but dry mechanisms with no bearing on habitability or life cannot yet be ruled out [7]. Megabreccia (e.g., Fig. 1c) comprised of diverse lithologies redistributed by impacts may be the oldest rocks at the Martian surface [16], but current orbital data cannot resolve the composition of individual clasts, and the degree to which these materials record impact hydrothermal processes remains contested [17,18]. Chloride salt flats (e.g., Fig. 1d) are widespread throughout the southern highlands [5], but we do not know whether the fluids that formed them were always hypersaline and inimical to life [19] or initially more dilute; the clay deposits associated with some chlorides [6] could imply the latter, but only if these minerals formed in the same epoch, which orbital data cannot resolve. Finally, the gypsum-rich dunes bounding the North Polar Layered Deposits (Fig. 1e) may record one of the youngest aqueous alteration episodes on all of Mars [6], but their precise age and origin are uncertain.

None of the materials displayed in Fig. 1 have been accessed by any landed mission to date, and none will be accessible (to our knowledge) to Curiosity in Gale crater. Furthermore, ***no two of these can be accessed at any single site yet known***. Fig. 1 illustrates only a subset of the 9–10 distinct aqueous environments documented by [6], and more have been identified since that publication. Notably missing from Fig. 1 (and from landing sites to date) are sedimentary deposits from deep paleo-lakes—both siliciclastic [20,21] and evaporitic [22]—and carbonate minerals from the Late [23] and earlier Noachian [24,25], which might give unique insights into Mars climate history [26].

Even if the approximate temperature, pH, salinity, water/rock ratio, and duration of liquid water in each environment described above were known, it would seem hubristic to claim that we could determine confidently which was most conducive to the origin or persistence of Martian life, and/or its subsequent preservation. But currently we have not even constrained many of these parameters at most sites. Doing so requires an assessment of mineral assemblages, chemistry, and sedimentary structures, achievable only *in situ.*

The Mars Exploration Rovers illustrate the rewards of *in situ* science. Spirit has identified acidic sulfates and nearly pure hydrous silica in soils surrounding the "Home Plate" structure in Gusev crater, interpreted as a reworked pyroclastic deposit [27-29]; these soils were invisible from orbit, and Home Plate was previously interpreted as lacustrine sediment from the inferred Gusev paleo-lake. Opportunity found that the hematite detected from orbit [2] resides mainly in a lag deposit of millimeter-sized spherules, interpreted as diagenetic concretions; these are eroding from sulfate-rich sediments deposited in eolian dune to interdune playa environments [30,31]. These first-order environmental characterizations required only a color camera and IR spectrometer for remote sensing, plus contact instruments to measure chemistry, mineralogy, and sub-mm textures. Sampling the diverse sites described above with similar rovers or with slight adaptations [32] would have both programmatic and budgetary advantages [33]. Doing so would be no more repetitive than probing the Amazon, Himalaya, Sahara, and Mariana Trench on Earth. The missions would not be MER-C, MER-D, …, but rather the Noachian Explorer, Mars (Paleo)Lake Lander, Modern Water Probe, etc., each certain to return unprecedented insights.

References: [1] Christensen P. R. et al. (2001) *JGR, 106,* 23,823–23,871. [2] Christensen P. R. et al. (2001) *JGR, 106,* 23,873–23,885. [3] Bridges J. C. et al. (2001) *SSR, 96,* 365–392. [4] Bibring J.-P. et al. (2006) *Science, 312,* 400–404. [5] Osterloo M. M. et al. (2008) *Science, 319,* 1651–1654. [6] Murchie S. L. et al. (2009) *JGR, 114,* E00D06. [7] McEwen A. S. et al. (2011) *Science, 333,* 740–743. [8] MEPAG ND-SAG (2008) *Astrobiology, 8,* 489–535. [9] NRC (2011) *Vision and Voyages for Planetary Science in the Decade 2013–2022.* [10] Poulet F. et al. (2008) *A&A, 487,* L41–L44. [11] Loizeau D. et al. (2007) *JGR, 112,* E08S08. [12] Tornabene L. L. et al. (2007) *7th Int'l Conf. on Mars,* Abstract #3288. [13] Wray J. J. et al. (2008) *GRL, 35,* L12202. [14] McKeown N. K. et al. (2009) *JGR, 114,* E00D10. [15] Noe Dobrea E. Z. et al. (2010) *JGR, 115,* E00D19. [16] McEwen A. S. et al. (2008) *AGU Fall Meeting,* Abstract #P43D-03. [17] Tornabene L. L. et al. (2009) *LPS XL,* Abstract #1766. [18] Grant J. A. et al. (2011) *Icarus, 212,* 110–122. [19] Tosca N. J. et al. (2008) *Science, 320,* 1204–1207. [20] Malin M. C. and Edgett K. S. (2003) *Science, 302,* 1931–1934. [21] Ehlmann B. L. et al. (2008) *Nature Geosci., 1,* 355–358. [22] Wray J. J. et al. (2011) *JGR, 116,* E01001. [23] Ehlmann B. L. et al. (2008) *Science, 322,* 1828–1832. [24] Michalski J. R. and Niles P. B. (2010) *Nature Geosci., 3,* 751–755. [25] Wray J. J. et al. (2011) *LPS XLII,* Abstract #2635. [26] Kahn R. (1985) *Icarus, 62,* 175–190. [27] Squyres S. W. et al. (2007) *Science, 316,* 738–742. [28] Yen A. S. et al. (2008) *JGR, 113,* E06S10. [29] Squyres S. W. et al. (2008) *Science, 320,* 1063–1067. [30] Squyres S. W. et al. (2004) *Science, 306,* 1709–1714. [31] Grotzinger J. P. et al. (2005) *E&PSL, 240,* 11–72. [32] Ehlmann B. L. et al. (2012) *this conference.* [33] Niles P. B. et al. (2012) *this conference.*