MARS GEOSCIENCE IMAGING AT CENTIMETER-SCALE (MAGIC) FROM ORBIT. M. A. Ravine, M. C. Malin, M. A. Caplinger, Malin Space Science Systems, PO Box 910148, San Diego, CA 92191-0148 USA.

Introduction: The **MA**rs **G**eoscience **I**maging at **C**entimeter-scale (**MAGIC**) investigation would be implemented as a Discovery-class mission to provide images of the martian surface at 5–10 cm/pixel, permitting resolution of features as small as 20–40 cm (Figure 1). For the price of one small landed mission, MAGIC would cross the divide between orbiter and lander, obtaining lander-esque views of thousands of locations on Mars, including those at elevations and latitudes not accessible to present landing systems. Using stereopairs, investigators could create virtual field sites from these data. Appropriately equipped, research workshop participants could take each other on virtual field trips to point out critical geological observations; rover and astronaut teams could familiarize themselves with the detailed particulars of a site in advance of arrival on Mars. Essentially, MAGIC provides opportunities to "land" at and investigate thousands of places on Mars, including those not likely to be reached by any other means in this century.

Landing, Field Operations, Sample Collection, and Ascent Support Objectives: MAGIC images would have sufficient resolution so as to be able to see an astronaut on the surface of Mars and to positively identify the final location of the Sojourner rover. MAGIC images are intended to help in strategic assessment, selection, and documentation of robotic and human field sites and sample locales. In particular, data can be collected to address:

- down-selection of candidate robotic and human field sites based on geologic observations, descent hazards, and vehicle trafficability;
- repeated pre-landing imaging to characterize potential eolian hazards (e.g., sand-blasting of field equipment; wind hazard for ascent vehicles) and benefits (e.g., dust removal from solar panels);
- detailed strategic planning of robot and astronaut sampling traverses at selected field sites;
- repeated post-landing documentation of these traverses when they are in progress; and
- documentation and tracking of the state of landed hardware.

Geoscience Objectives: Critical geologic and geomorphic details—diagnostic of process, environment, habitability, and/or relation to liquid water—are commonly just out of reach in the highest resolution images acquired from orbit about Mars. This is evident, for example, when one considers that eolian crossbeds in ancient, sedimentary rock observable from images acquired by the cameras aboard the Opportunity rover [1] cannot be resolved in 30 cm/pixel HiRISE images; or when one considers the challenges of confirming the hypothesis that debris flows (containing sediment and liquid water) occurred in martian mid-latitude gullies when, as noted by Conway *et al.* [2], the highest resolution images usually do not resolve the levees expected to be present on these landforms.

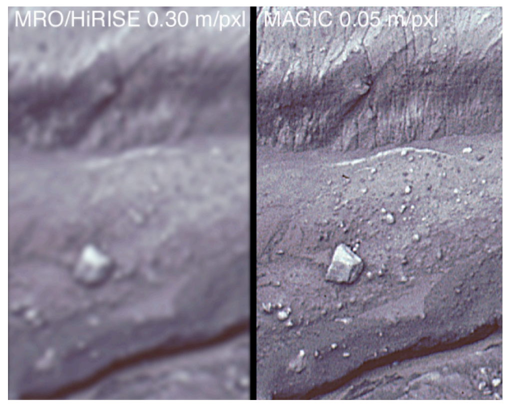

Figure 1. The ability of MAGIC to resolve small scale features as compared with HiRISE is illustrated in these simulated views of the Pine Creek mudflows at Mount St. Helens.

Each successive increase in spatial resolution of spacecraft images allows us to see the results of geologic processes that occurred more recently in time. On Mars, the successive increases in spatial resolution have also provided unprecedented opportunities to discern details—recorded in stratified rocks—of processes and environments in the very ancient times.

MAGIC is foremost a sedimentology experiment. The main focus is on advancing Mars science by examining sediments, stratigraphic relations, and the geomorphologic attributes of sedimentary rocks and younger deposits (e.g., gullies, outflow channels, polar materials) to distinguish between the results of processes involving water, ice, wind and other fluids in sedimentary transport, deposition, and landscape denudation in both the very recent and very distant past. Key science issues center on the present availability of liquid water and the nature of past and present habitable environments, such as the role of liquid water and/or other fluids in formation and maintenance of geologically young or currently active mid-latitude gullies [3] and recurring slope lineae [4]; and distinction of sedimentary rocks formed from materials deposited in subaerial versus subaqueous (or subliquid) environments (and the role of ice, ground ice, and ground water in these rocks).

In order of scientific priority, the MAGIC science objectives are to investigate:

- *Fluids:* Determine the physical properties of fluids that created conduits and/or flows and transported sediment across the martian surface.
- *Strata:* Identify the processes, nature, and time-ordered succession of paleoenvironments in which stratified materials were deposited.
- *Ice:* Examine landforms proposed to have been formed by processes involving H_2O and CO_2 ice, including polar terrain, periglacial features, and mid-latitude geomorphology.
- *Dynamic Processes:* Monitor and measure the results of dynamic processes such as dune and ripple movement, wind and slope streaks, dust devils, and seasonal polar frost/defrost patterns.
- *Landscape Evolution:* Identify processes responsible for exposure and denudation of layered rock outcrops, examine hillslope evolution, determine the geomorphic processes that have acted upon the diversity of martian terrain, including gravity, wind, volcanism, and impact cratering.

Implementation: The key factors in achieving a particular Mars orbiting camera surface resolution are altitude, aperture and dwell time. The strategy for achieving 5–10 cm/pixel would be to operate at the lowest maintainable altitude with the largest aperture telescope and longest dwell time that could be accommodated for a given mission cost envelope. The values for each parameter depends on optical systems engineering and the specifics of Mars.

Altitude: Operation of MAGIC at the minimum practical altitude is motivated by the fact that resolution decreases linearly with target distance. For the purpose of the point design presented here, we consider an altitude at which there is no appreciable short-term loading on the spacecraft from the atmosphere. This is necessary to avoid non-deterministic loads during a period when it has to maintain sub-microradian pointing stability. Based on the aerobraking experience from Mars Global Surveyor, Mars Odyssey and the Mars Reconnaissance Orbiter (MRO), here we assume this number is 170 km. Note that there would still be issues with the long term stability of an orbit at this height. Providing adequate flexibility in latitude sampling at a sustainable cost in orbit maintenance over the course of the mission are key aspects of mission design; the exact strategy is not addressed here.

Aperture: The relationship between aperture and resolution requires consideration of both the performance of the optics and how the signal provided by those optics are sampled. For the point design presented here, we use the same ratio of optics point spread function (PSF) to pixel scaling as the MRO HiRISE. From the nominal altitude of 300 km, HiRISE images have a ground sample distance of 30 cm/pixel. Given HiRISE's 50 cm aperture, the diameter of its point spread function is ~1.5 pixels.

Dwell time: Implicit in any spatial resolution requirement is that the pixels values must have an adequate signal to noise ratio (SNR). With orbital imaging, the ground track velocity constrains integration time, directly limiting SNR. Approaches for increased dwell time with a fixed ground track velocity include Time Delay Integration (TDI), a method by which the dwell time is increased by electronically shifting the charge accumulation location on the detector to track the motion of the scene, and slewing the entire instrument to reduce the effective scan rate. For a fixed nadir-pointing instrument orbiting Mars, 5–10 cm per pixel corresponds to a few tens of microseconds of dwell time. While it is likely that neither TDI nor slewing, by themselves, would be adequate to increase dwell time to get the required SNR (~10 milliseconds for an SNR of ~100), a combination of both would.

Example (Point Design): To illustrate how altitude, aperture and dwell time play off each other, we consider a specific point in the design space: imaging of Mars from orbit at 7 cm/pixel. That scale with the above PSF to pixel ratio and altitude would require an aperture of 1.2 m. While is this substantial, it is smaller than (the planet-finding Discovery mission) Kepler's 1.4 m primary mirror. The ground-track-velocity-dictated dwell time for a 7 cm/pixel system is ~20 microseconds. Based on previous experience, a practical number of lines of TDI to would be 128. Also, slewing the instrument to increase the dwell time by a factor of four would yield the target SNR without significantly affecting viewing geometry. While the detailed requirements on MAGIC differ from Kepler's (*e.g.*, MAGIC would have a much, much smaller field of view), the similar scale of the driving system element, the primary mirror, show that the MAGIC concept is compatible with a Discovery-class mission. A MAGIC orbiter might also carry a camera for daily global weather monitoring, an infrared mineral mapper, and/or a context camera to find changes (e.g., new impact craters [3]) occurring on Mars during the mission.

References: [1] Grotzinger J. P. et al. (2005) *EPSL 240,* 11–72, doi:10.1016/j.epsl.2005.09.039. [2] Conway S. J. et al. (2011) in *Martian Geomorphology, Geol. Soc. London Spec. Publ. 356,* 171–201, doi:10.1144/SP356.10. [3] Malin M. C. et al. (2006) *Science 314*, 1572–1577, doi:10.1126/science.1135156 [4] McEwen A. S. et al. (2011) *Science 333*, 740–743, doi:10.1126/science.1204816.