MRO's HIGH RESOLUTION IMAGING SCIENCE EXPERIMENT (HiRISE): SCIENCE EXPECTATIONS.
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Introduction: The Mars Reconnaissance Orbiter (MRO) is expected to launch in August 2005, arrive at Mars in March 2006, and begin the primary science phase in November 2006. MRO will carry a suite of remote-sensing instruments and is designed to routinely point off-nadir to precisely target locations on Mars for high-resolution observations. The mission will have a much higher data return than any previous planetary mission, with 34 Tb of returned data expected in the first Mars year in the mapping orbit. The mapping orbit is nearly polar, 255 x 320 km above the surface, 12 orbits per day.

The HiRISE camera, described by Delamere et al. [1], features a 0.5 m telescope, 12 m focal length, and 14 CCDs. Basic capabilities are summarized in Table 1.

Table 1. HiRISE Capabilities

Ground Sampling Dimension (GSD)	30 cm/pixel (at 300 km altitude)
Swath width (Red bandpass)	6 km (at 300 km altitude)
3-Color swath width	1.2 km (at 300 km)
Maximum image size	20,000 x 65,000 pixels
Signal:Noise Ratio (SNR)	>100:1
Color Bandpasses	Red: 550-850 nm Blue-Green: 400-600 nm NIR: 800-1000 nm
Stereo topographic precision	~20 cm vertical precision over ~1.5 m^2 areas
Pixel binning	None, 2x2, 3x3, 4x4, 8x8, 16x16; each CCD separately commanded.
Compression	Fast and Efficient Lossless Image Compression System (FELICS)

HiRISE operations and data processing are described by Eliason et al. [2]. We are encouraging input from the science community on finding the best locations to target HiRISE images. Ideally each target would result from a mini research effort with analysis of MOC, THEMIS, MOLA, and other datasets as they become available (MER, Mars Express, and especially from MRO). In spite of MRO's relatively high data rate, the very high resolution of HiRISE severely limits the areal coverage of Mars that we can achieve. We expect to cover ~1% of Mars at better than 1.2 m/pixel, ~0.1% at 0.3 m/pixel, ~0.1% in 3 colors, and ~0.05% in stereo. Our major challenge is to find the key contacts, exposures, and type morphologies to observe.

We expect to acquire ~10,000 observations in the primary science phase (~1 Mars year), including ~2,000 images for 1,000 stereo targets. Each observation will be accompanied by a ~6 m/pixel image over a 30 x 45 km region acquired by MRO's context imager, built and operated by Malin Space Science Systems. Many HiRISE images will be full resolution in the center portion of the swath width and binned (typically 4x4) on the sides. This provides two levels of context, so we step out from 0.3 m/pixel to 1.2 m/pixel to 6 m/pixel (at 300 km altitude).

The HiRISE team is highly motivated to maximize the absolute science return from this experiment. We plan to (1) collect the best possible dataset; (2) process and analyze the data and publish results in a timely manner; (3) release all data ASAP to the science community and public; (4) acquire and analyze observations to support future Mars exploration; (5) foster the development of young scientists; and (6) encourage future scientists and public support for science via Educational and Public Outreach (E/PO). For more on HiRISE E/PO plans, see Gulick et al. [3].

The purpose of this abstract is to discuss key issues in understanding Mars for which we think HiRISE can make a significant contribution.

Science Objectives and Capabilities. The high-level science objectives of MRO are to (1) characterize the current climate and mechanisms of climate change, (2) determine the nature of complex layered terrain, (3) identify water-related landforms, (4) search for sites showing evidence for aqueous and/or hydrothermal activity, and (5) identify and characterize sites with the highest potential for landed science and sample return by future missions. Given these objectives, the key HiRISE capabilities in order of priority are:

(1) Achieve the best possible spatial resolution and detection of surface features. With a ground sampling dimension between 25 and 32 cm/pixel

along with a narrow point-spread function (PSF) and high signal to noise ratio (SNR) we can detect most 1-meter-scale objects and begin to characterize objects or landforms with dimensions of 2 meters. The HiRISE PSF will be less than 2 pixels wide at half max when spacecraft jitter is negligible.

(2) Achieve high-resolution topographic data from stereo images and Digital Elevation Models (DEMs). We expect to achieve a vertical precision of ~0.2 m over areas of ~5 x 5 pixels (~1.5 m). In some cases photoclinometry can be used to sharpen this topographic mapping to the pixel scale [4].

(3) Acquire observations in up to 3 colors with high radiometric fidelity, for photometric studies such as identification of color/albedo units and photoclinometry. HiRISE color images should be especially useful for coanalysis with spectral image cubes acquired by MRO's vis-IR spectrometer CRISM [5]. HiRISE color images at sub-meter scales, correlated to mineralogic signatures of interest in the search for life, may enable identification from orbit of specific outcrops of interest for *in situ* analysis or sample return.

To achieve the highest spatial resolution and precision stereo, the layout of CCDs was carefully designed to enable us to derive 2 types of information: (1) rates of spacecraft jitter during the HiRISE integration time (up to ~12 ms) and how it broadens the PSF in the downtrack and crosstrack directions, and (2) geometric distortions introduced by spacecraft pointing instabilities over timescales longer than 12 ms. This information will enable (1) PSF deconvolution to sharpen the images (and make the resolution more uniform as a function of time, i.e. down an image); and (2) geometric reconstruction to subpixel accuracies to enable precision stereo. The lack of useful information for geometric correction of MOC images is the major limitation in their usefulness for quantitative topographic measurements [4].

Landing Site Safety and Trafficability. A prime objective of HiRISE is to identify potential hazards to landed missions. The size and shape of boulders and other topographic obstacles considered dangerous varies from mission to mission, but, for example, 0.5-meter high boulders were considered potentially fatal to the 2001 lander (which may yet rise from the ashes as the Mars Scout mission called Phoenix [6]). HiRISE can detect meter-scale objects and measure their heights. Furthermore, the hazard may depend on rock angularity; at least 5 or 10 pixels across an object is needed to characterize its shape, so HiRISE can characterize the shape of rocks larger than ~2 or 3 meters.

MOC is able to detect giant boulders or detached chunks of bedrock larger than ~5 m diameter, but boulder counts are probably incomplete for objects smaller than ~10 m. Such large objects only occur in limited geologic settings such as near the base of steep slopes that are less than a few km high or near the rims of impact craters. For MER landing site studies it has been necessary to rely on extrapolations based on observed giant boulders using the size-frequency distribution of boulders at previous Mars landing sites and at Earth analog terrains, along with estimates of rock abundance from thermal models [7]. The thermal remote sensing cannot distinguish cobbles from boulders or recognize boulders whose tops are covered by more than a few cm of fine materials.

Rover trafficability is a function of slopes on scales larger than the rover and roughness on scales comparable in size to the wheels. HiRISE can reveal slopes and roughness to 1-meter scales; estimation of roughnesses on smaller scales is at least a smaller extrapolation than is currently required. Surface slopes over 5-10 m scales are also important to both roving and lander safety, for which HiRISE DEMs will be more than adequate.

HiRISE will of course image past landing sites including those from Viking, Pathfinder, Beagle 2, and MER. These detailed orbital views may resolve mysteries and lead to reconsideration of previous interpretations. These comparisons will provide essential ground truth to HiRISE interpretations.

Mars Science Issues. Many fundamental questions about Mars remain controversial. These are exciting times, with a diversity of paradigms churning in the wind and water. The value of high-resolution imaging to addressing these issues (and raising new controversies) has been well demonstrated by MOC [8].

Table 2: MOC-HiRISE Comparisons

	MOC	HiRISE
GSD	1.5 m/pixel	0.3 m/pixel
Swath width	3 km	6 km
Typical SNR	50:1	150:1
Colors	1	3
Local Mean Solar Time	2 PM	3 PM
Context imaging	200 m/pixel	6 m/pixel
Stereo vertical precision	?	0.2 m

HiRISE is intended to enable advances well beyond MOC results via significant improvements in several attributes (Table 2). Below we discuss a sample of the science issues of importance to future Mars exploration with an emphasis on astrobiology.

When and where have there been long-lived bodies of water on Mars? There is convincing evidence (to most Mars scientists) that water carved the outflow channels and valley networks, and must have ponded in closed basins. However, it is less certain that bodies of water persisted at the surface for significant lengths of time, creating environments favorable to life. Key to this debate is the origin of relatively fine layers seen in many locations [9]. Leading interpretations include lake sediments or windblown or airfall materials. Either interpretation implies fine particle sizes, far below HiRISE resolution, but perhaps HiRISE could resolve sedimentary structures like giant cross-bedding. HiRISE will provide many new details on these strata, but it may not provide "imaging at definitive scales" in this case. Sedimentological interpretations are often controversial even when the sediments have been studied in great detail in the field (by more than 1 research group). CRISM compositional data in combination with HiRISE might lead to more convincing interpretations, at least to the level of whether or not a long-lived body of water was likely.

Another key issue is when the fine layers were emplaced, with estimates ranging from Noachian [9] to Amazonian [10]. Details of how the material is eroded or on the abundance of embedded craters should help, but controversy may persist until sample return or *in situ* age dating is achieved.

How recently did the mid-latitude gullies form? Malin and Edgett [11] proposed that the gullies are young (probably less than 10^6 yrs) because there are usually no superimposed impact craters and because gully materials are superimposed over dunes and polygonally-patterned ground, which are young features on Earth (10^3 to 10^4 yrs). This leaves open the possibility that gullies are forming today, and that liquid water may exist very near the surface, a possibility of great significance to astrobiology. HiRISE can search for changes in the surface topography (compared with previous MOC or HiRISE images) that would indicate current activity of gullies. Evidence for current formation of dunes or patterned ground would also help address this issue.

Hydrology: How much water was released? The outflow channels clearly had enormous peak discharge rates (Q), but estimates of Q differ by orders of magnitude. One key morphology that helped to constrain the hydrology of the Channeled Scablands floods was the occurrence and properties of subaqueous dunes (also called "giant current ripples") [12]. Some excellent candidates for subaqueous dunes have been identified in Athabasca Valles [13], but it is not yet possible to prove that these are not eolian dunes. If HiRISE detects boulders in the dunes, then we will know that the transport medium was water, not air. MOC has detected very few boulders in Martian channels [8], but that may be a resolution limit and HiRISE could detect many boulder deposits. Slowly-cooled lava flows tend to quickly disaggregate along joints into ~1- or 2-meter sized blocks [14]. If there are larger boulders, HiRISE will enable some characterization of the degree of rounding, which is related to transport distance. HiRISE color images could enable tracing boulders back to their source regions. In addition to studying boulders, HiRISE topographic data will enable detailed hydraulic modeling.

What is the polar CO_2 inventory? The "swiss cheese" terrain on the residual south polar ice cap has been observed to retreat 1 to 3 meters in 1 Mars year, apparently via sublimation of CO_2 ice [15]. Continued monitoring of these changes and high-resolution topographic measurements will enable us to better quantify rates of CO_2 loss and the total CO_2 inventory available to facilitate periodic climate change.

Can we trust small craters for age constraints? Planetary geologists are desperate for constraints on the relative and absolute ages of geologic units and their rates of modification. Geologic history is a chronicle of past events; history without dates is like music without sounds. All of the questions discussed in this abstract are affected by this issue. Our only remote-sensing tools are superposition relations, time-dependent surface processes like the disappearance of crater rays, and counts of impact craters. Crater counts have been widely used and with great success for large craters, but for features covering small areas or for young surfaces, only small craters are present. Via counts of small craters it has been concluded that there was large-scale volcanism and flooding in the Cerberus region in the very recent past (<10 Ma) [13, 16].

However, there are several major problems with the statistics of small craters: (1) primary craters may be confused with secondary craters; (2) small craters are easily erased or buried, for example by eolian processes; (3) small craters may have endogenic origins, and (4) the atmosphere must screen out small bodies and affect the crater distribution below some diameter cutoff. Small craters (< 1 km diameter) on Mars may be dominated by secondaries [17], which are highly nonuniform in space and time and cannot be treated as independent random events. The uncratered gullies and flow lobes could be as old as 100 Ma if most small craters are secondaries.

The improved spatial resolution and topographic capability of HiRISE will help address these issues via better discrimination between primaries and secondaries, improved understanding of eolian processes, and improved ability to discriminate between impact and endogenic craters. Extending crater counts to smaller diameters may also reveal clear evidence for atmospheric screening of small bodies, perhaps varying with altitude or time (e.g., climate change).

When and where did volcano-water interaction occur? Mars is fundamentally a volcanic planet. Remote spectroscopic data, in-situ chemical data from landers, and the Mars meteorites all point to predominantly basaltic compositions. Altered mineralogies (i.e. palagonitic spectra) suggest significant water-lava interaction, but when and where did this occur? HiRISE should make major contributions via images and topography of key morphologies such as rootless cones, and via color images that show precisely where the altered units reside, such as particular layers in Valles Marineris and elsewhere.

Were there vast ice sheets? Kargel and Strom [18] first proposed that thick, continent-sized ice sheets were present over the polar regions of Mars. If correct, this hypothesis has major implications for paleoclimates. Glacial moraines are characterized by poorly-sorted mixtures of particle sizes up to large boulders, so HiRISE should see clear evidence for this type of deposit. There is a rich suite of other meter-scale morphologies associated with glaciers, so HiRISE should have much to contribute to this important debate.

What was the origin of the Vastitas Borealis Formation? The northern plains are covered by poorly-understood materials interpreted in a variety of ways by different workers. One interpretation is that these are ocean sediments [e.g., 19]. If correct, the sediments should have fine grain sizes except for widely scattered ice-rafted boulders. The detection of abundant boulders in these deposits might favor direct deposition from floods or mudflow deposits. However, the history may be complex and HiRISE can only sparsely sample these vast plains, so this issue may continue to be controversial. HiRISE will certainly provide a rich set of observations on periglacial processes in the northern plains [20].

What is the recent climate history recorded in polar layered deposits? MOC images resolve beds in the polar layered deposits (PLD) down to the resolution limit of the camera [8]. HiRISE images of the PLD are therefore likely to show stratigraphy at finer scales than previously observed. Similarly, higher-resolution images of the PLD will be useful in studying the deformation (faulting and folding) of the PLD [21]. Such observations may be used to constrain theories of recent climate changes on Mars.

What is the efficacy of current eolian activity? Dune migration has not been seen in MOC-Mariner 9 comparisons over several decades [22] nor in MOC-MOC comparisons over a few years [23]. Failure of slip faces of the dunes has been noted [8]. With higher resolution, we might very well see dune motion, thereby providing calibration of the efficacy of aeolian processes on Mars in the present day.

Summary. HiRISE will enable us to address a wide range of issues about the geologic and climatic evolution of Mars. Probably the most significant contributions will result from unexpected discoveries.

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