MGS MOC: FIRST VIEWS OF MARS AT SUB-METER RESOLUTION FROM ORBIT. M. C. Malin and K. S. Edgett, Malin Space Science Systems, PO Box 910148, San Diego, CA 92191-0148 USA.

Introduction: The Mars Global Surveyor (MGS) Mars Orbiter Camera (MOC) is now capable of obtaining images with sub-meter per pixel spatial resolution. In such images, the two Mars Exploration Rovers (MER) can be seen from orbit, 380–400 km away (Fig. 1a). These images also permit testing of hypotheses regarding a variety of martian landforms and geologic materials. MOC was designed to obtain images with spatial resolution as high as ~1.5 m/pixel from its nominal altitude orbit, using spacecraft motion to sweep a single line detector array across a target area [1]. In 2003 and 2004, operators of MOC and MGS pioneered an approach that allows MOC to obtain images with ~50 cm/pixel spatial resolution in the downtrack dimension. Images acquired using the cPROTO (compensated Pitch and Roll Targeted Observation) approach, effectively, provide sub-meter resolution views of Mars.

cPROTO Maneuver: To acquire a cPROTO image, the entire MGS spacecraft is moved in pitch and roll directions. A typical image covers an area of about 3 by 3 km. Owing to as-yet unresolved uncertainty in spacecraft motion, specific targets within a 3x3 km area are often missed by more than 2 km. In other words, the majority of cPROTO images do not hit their intended targets; 2–4 acquisitions are often needed to cover a feature of interest. During normal operations, MGS keeps its nadir deck, on which the MOC is fixed/mounted, pointed toward the planet. To do so, the spacecraft rotates about its Y-axis once per orbit. For cPROTOs, this rotation rate is changed by looking forward a bit and speeding up the spacecraft to stare at the target location while MGS flies over it, before returning to the downward stare. In this way, the apparent forward speed of the spacecraft is reduced, allowing either a longer dwell time per MOC image line (which improves signal to noise and thus image quality), multiple-samples at a given dwell time (increasing the spatial sampling in the down-track direction), or both. Operationally, we command the spacecraft to dwell 6 times longer than normal over the target, dividing this between sampling 3 times as the spacecraft covers a distance of 1.5 meters (downtrack) on the ground, and increasing the amount of time each sample represents by a factor of 2 (increasing image quality by 40%). The result is a sharper image with ~50 cm/pixel downtrack and ~1.5 m/pixel crosstrack. The “c” in “cPROTO” is for planetary motion compensation. While MGS is pitching, rolling, and moving along its orbit, Mars is rotating underneath it. The pitch and roll are timed to account for the rotation of Mars, as well as the desired image resolution and target location.

Limitations: Opportunities to acquire cPROTO images are limited by spacecraft communication schedules, because the spacecraft cannot communicate with Earth during a cPROTO maneuver, and by spacecraft solar power, because the solar panels cannot point at the Sun when a cPROTO is being executed. The size of a cPROTO image is limited by how much data the MOC can collect and place in its internal buffer, and the selection of a cPROTO target is limited by atmospheric opacity, solar illumination of the surface, and protection of MOC’s optical system from direct sunlight. Given these limitations, only certain parts of Mars are accessible to cPROTO imaging at any specific time during the year. Furthermore, even after a target is selected, it is possible that the image will miss the target or that other factors (gain/offset selection, unexpected clouds/dust storm) will contribute to the difficulty in achieving a desired goal.

Initial Results: The first 3 sub-meter images were PROTO (no compensation for Mars rotation). A total of 69 PROTO and cPROTO images were acquired and received from May 2003 through December 2004. A product of MOC science goals and the limitations described above, the majority of cPROTO images have thus far focused on 6 specific target types: landing sites, gullies, sedimentary rocks, fretted terrain valley floor textures, north polar residual cap and layered materials, and eolian features. Other images examined outflow channel landforms, ridged-textured materials associated with sedimentary rocks, and products of mass movement on slopes. Owing to the limitations described above, our investigation of all of these subjects is incomplete and awaits acquisition of additional images.

Landing Sites. After landing, both MER sites were imaged and showed the locations of the lander, heat shield, and parachute/backshell. Bounce marks were evident at the MER-A site, and rocket blast results were seen at the MER-B site. As the MER missions were extended, MOC cPROTO image mosaics became critical for long-range traverse planning. Later cPROTO images documented the rovers’ tracks. Other PROTO and cPROTO efforts imaged the locations of the Viking and Mars Pathfinder landing sites. Two attempts were made to image a candidate Beagle 2 site; the second attempt showed that the candidate was a small impact crater with—unusual for that part of Isidis Planitia—a small dark dune in it. As of 7 January 2005, no additional Beagle 2 candidate sites have been identified. cPROTO images of candidate locations for the Mars Polar Lander are scheduled to be attempted in 2005.

Gullies. In 2004, there was a narrow period (May through July) when cPROTO acquisition limitations permitted imaging of south mid-latitude gullies. A goal of the cPROTO campaign is to test hypotheses about the genesis and evolution of the types of gullies first described by Malin and Edgett [2]. In particular, the presence or absence of boulders transported through gully channels and deposited in their depositional aprons provides constraints regarding the rheologic properties of the transporting fluids. No boulders have yet been observed in the 8 cPROTO images that include a gully apron area (Fig. 1b).

Sedimentary Rocks. Sedimentary rock outcrops are common all across the surface of Mars [3]. cPROTO images of sedimentary rock sites often reveal more and thinner layers than evident at lower spatial resolution, and they show something that was not clearly resolved in previous MOC images—the shedding of boulders from steep slopes at sedimentary rock outcrop sites (Fig. 1c). The occurrence and small size of the boulders provides insights into the physical properties of the sedimentary rocks.

Fretted Terrain Valley Floors. Fretted terrain valley floors exhibit odd textures resembling corncobs and brains [4]. Half a dozen cPROTO images were acquired to provide insights regarding these landforms. Individual mounds and hills within the textured, lineated valley floor areas exhibit smooth surfaces at the limit of cPROTO resolution (Fig. 1d). No debris/talus is evident in the depressions between the mounds, suggesting that if their genesis involves erosion, the materials are quickly transported away.

North Polar Residual Cap and Polar Layers. Northern summer arrived during 2004, permitting sub-meter imaging of north polar targets. The residual ice cap surfaces are pitted (Fig. 1e); the floors of pits are darker than their walls and the surfaces outside the pits, suggesting that the pits are trapping non-volatile material (*e.g.*, dust). North polar layers exposed in the arcuate scarp in Chasma Boreale are distinctly grouped into 3 units, the middle of which appears to be a source for dark sand. Talus shed from this scarp includes several large blocks (boulders).

Eolian Features. No specific eolian targets were selected in 2003–2004, but many cPROTO images show large, ripple-like bedforms, and one north polar image includes sand dunes. Large ripples analogous to terrestrial granule ripples formed by grains transported by traction occur on the dunes in the north polar image (Fig. 1f).

References: [1] Malin M. C. (1992) *JGR, 97,* 7699–7718. [2] Malin M. C. and Edgett K. S. (2000) *Science, 288*, 2330–2335. [3] Malin M. C. and Edgett K. S. (2000) *Science, 290*, 1927–1937. [4] Malin M. C. and Edgett K. S. (2001) *JGR, 106*, 23429–23570.

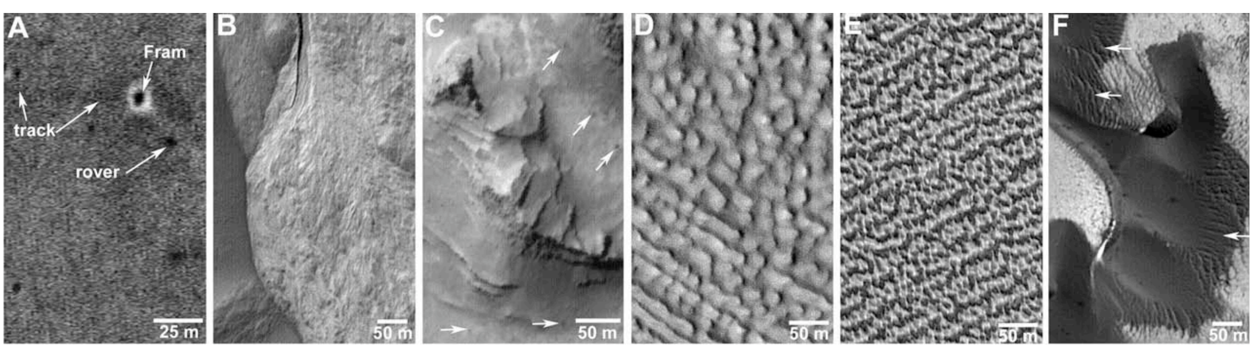

Fig. 1. (A) MER-B Rover (from MOC image R16-02188). (B) Portion of a gully apron (R17-01367). (C) Boulders (arrows) shed from sedimentary rock outcrop in southwest Candor Chasma (R18-01711). (D) Fretted terrain valley floor material (R19-01803). (E) North polar residual cap (R23-00003). (F) Dunes and "granule" ripples (arrows) (R23-00143). All images shown here are sub-frames of the MOC image noted. Images re-sized to fit this page.