Pancam Imaging of the Mars Exploration Rover Landing Sites in Gusev Crater and Meridiani Planum.

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Introduction: The Mars Exploration Rovers carry four Panoramic Camera (Pancam) instruments (two per rover) that have obtained high resolution multispectral and stereoscopic images for studies of the geology, mineralogy, and surface and atmospheric physical properties at both rover landing sites. The Pancams are also providing significant mission support measurements for the rovers, including Sun-finding for rover navigation, hazard identification and digital terrain modeling to help guide long-term rover traverse decisions, high resolution imaging to help guide the selection of *in situ* sampling targets, and acquisition of education and public outreach imaging products.

Pancam is a multispectral, stereoscopic, panoramic imaging system consisting of two digital cameras mounted on a mast 1.5 m above the martian surface. The mast allows Pancam to image the full 360° in azimuth and ±90° in elevation. Each Pancam camera utilizes a 1024×1024 active imaging area frame transfer CCD detector array. The Pancam optics have an effective focal length of 43 mm and a focal ratio of *f*/20, yielding an IFOV of 0.27 mrad/pixel and a FOV of 16°× 16°. Each rover's two Pancam "eyes" are separated by 30 cm and have a 1° toe-in to provide adequate stereo parallax. Each eye also includes a small 8-position filter wheel to allow surface iron mineral studies, multispectral sky imaging, and direct Sun imaging, in the 400-1100 nm wavelength region. Additional instrument details can be found in [1].

Observations, Data Reduction, and Calibration: Pancam has substantial commanding and measurement flexibility, and each set of imaging observations is tailored in terms of filters, resolution, and compression to meet specific science objectives as well as resource constraints (power, duration, data volume). Initial observations at each landing site focused on quick-look RGB images ("postcards") within the first few sols, and then transitioned into the acquisition of an initial 360°×45° four-color (482, 535, 753, 1009 nm) and stereo (at 753 nm) "Mission Success" panorama.

To meet data volume and downlink time constraints, most Pancam images must be compressed in a lossy fashion. Some compression is obtained by scaling many of the original 12-bit images down to an 8-bit range using an approximately square-root algorithm that prevents the encoding of detector shot noise [1]. Most images are further compressed using the rover's onboard lossy wavelet-based compression algorithm (ICER) [2]. Additional data volume savings are sometimes obtained by downsampling images in some filters by 2× or more (yielding 512×512 or smaller images) or subframing parts of the full field of view.

The compression scenario for the earliest imaging and the Mission Success panoramas was 12 to 8 bit scaling followed by 16:1 ICER compression for the full-frame 753 nm stereo images, and the same scaling/ICER combination plus 2× downsampling for the 482, 535, and 1009 nm images. Despite these seemingly-harsh lossy compression rates, an impressive amount of detail is still retained in the initial Pancam imaging data from each site. Subsequent Pancam imaging sequences have almost always used 12 to 8 bit scaling combined with compression factors of 4:1 to 8:1, and a small number of images have been acquired using lossless compression in order to preserve the highest degree of fine-scale detail.

Raw Pancam images must undergo instrumental corrections for bias, dark current, electronic shutter smear, and flatfield variations and then must be converted to radiometric units. Bias signal has been found to be small in the images acquired to date (only a few tens of DN in the original 12-bit data), and it and the electronic shutter smear signal [1] are often removed onboard by the acquisition of near-simultaneous "zero exposure" images. Similarly, dark current has been observed to be small in the data acquired so far (from negligible up to a few hundred DN maximum in the original 12-bit data), as predicted for the typical CCD temperatures at which both Pancam systems have been operating (-30°C to 0°C). If not commanded to be removed by on-board processing, bias, dark current, and flatfield variations are all modeled and removed using the results of an extensive pre-flight calibration campaign [3]. No "bad pixel" corrections have been applied to Pancam images, because only a handful of bad pixels have been seen in pre-flight calibration or flight operations. Notably, the elevated solar flare activity experienced by the rovers during their cruise to Mars does not appear to have had any negative effects on Pancam or any of the other imaging detectors.

Pancam images are calibrated to absolute radiance (W cm^{-2} sr^{-1} nm^{-1}) using pre-flight radiance coefficients derived from integrating sphere observations and corrected for detector and electronics temperature variations. Estimated uncertainties on radiance values are continuing to be refined and are currently ~5% for the narrowband geology filters and ~10% on the wider short- and long-wavelength filters (482, 1009 nm).

Pancam images are also calibrated to either radiance factor (I/F, where I = radiance received by the detector and πF = radiance of sunlight incident on the top of the Martian atmosphere) or relative reflectance using near-simultaneous observations of the Pancam Calibration Target and a model of the target's photometric behavior. The target, based on the Imager for Mars Pathfinder target [4], contains three grayscale rings of 20%, 40%, and 60% reflective material and a shadow post to allow simultaneous observations of direct and diffuse illumination. The photometric and spectroscopic properties of the target materials were extensively characterized in pre-flight measurements [1,3]. Observations of the target on Mars are used to derive a 3-point relative reflectance calibration using a process analogous to the derivation of R* described by [5] for Imager for Mars Pathfinder observations. This calibration approach yields what would be called Lambert albedo values if one assumes that the surface regions being measured are Lambertian. Near-simultaneous imaging of the target and the scene also provides a first-order diffuse illumination correction, for surfaces that are parallel to the surface of the target (*i.e.,* most of Gusev and some of Meridiani so far...).

Initial Pancam Results: MER-A "Spirit" Gusev Landing Site: The Gusev Pancam Mission Success pan was acquired prior to rover standup on Sols 3 through 5. Much of this panorama was re-acquired on Sols 6 through 10 at a different geometry after rover standup, to provide context imaging to accompany the Mini-TES Mission Success panorama observations [6].

The Spirit landing site is on a rocky and gently-rolling plain within a region of slightly darker wind streaks near the center of Gusev crater. The average 750 nm albedo of the landing site is 0.26±0.04, which is consistent with the MGS/TES-derived bolometric albedo of the region (0.19 to 0.23 [7]). The Pancam images reveal features from mm-scales near the rover out to meter-scales within hills and knobs on the horizon. Coarse stereo ranging solutions have been derived for objects out to 150-200 m from the rover, providing detailed information for upcoming traverse decisions. The 11-band Pancam color of the rocks and soils is generally consistent with previous telescopic and spacecraft observations of dust-dominated surface regions [*e.g.,* 8-11], though isolated lower albedo pebbles, rocks, and soil patches show Pancam near-IR spectra consistent with a more mafic component [*e.g.,* 12]. High spatial resolution images have also revealed interesting and as-yet enigmatic soil textures and physical properties in regions where the soil has been disturbed by airbag retraction or the rover wheels.

Initial Pancam Results: MER-B "Opportunity" Meridiani Landing Site: The Meridiani Pancam Mission Success panorama was acquired prior to rover standup on Sols 2 and 3. The Opportunity landing site is within a small and shallow (~2 m deep, ~20 m diameter) low albedo crater surrounded by a flat low albedo plain. The average 750 nm albedo of the landing site is 0.15±0.02, consistent with the MGS/TES-derived low bolometric albedo of the region (0.11 to 0.15 [7]). The initial panorama provides geologic and compositional information only out to the crater rim and a few isolated regions on the distant horizon. Pancam images have revealed detailed morphologic information on a low-relief outcrop of brighter, reddish, and finely layered rocks that span ~180° in azimuth near the crater's rim. The Pancam spectral properties of the brightest rocks in the outcrop are similar to those of bright deposits found at the Viking and Pathfinder sites, suggesting the possibility that at least some of the rocks may be indurated dust [8,10,11]. Other enigmatic findings include soil deposits brightened and reddened by airbag compaction, and mm- to cm-scale pebbles/rocks, some spherical, that exhibit significant spectral diversity across Pancam wavelengths.

More detailed overviews of the geology, mineralogy, and atmospheric properties of both sites can be found in [13-17] and related papers in this volume.

References: [1] J.F. Bell III *et al.* (2003) *JGR 108* (E12), 4-1; [2] J.N. Maki *et al.* (2003) *JGR 108* (E12), 12-1; [3] J.F. Bell III *et al.* (2003) MER Pancam Calibration Report, JPL Document D-19826; [4] P. Smith *et al.* (1997) *JGR 102,* 4003; [5] Reid, R.J. *et al.* (1999) *JGR 104,* 8907; [6] P.R. Christensen *et al.*, this volume; [7] M. Golombek *et al.*, this issue; [8] R. Arvidson *et al.* (1989) *JGR 94,* 1573; [9] J.F. Bell III *et al.* (1997) *JGR 102,* 9109; [10] H.Y. McSween Jr. *et al.* (1999) *JGR 104,* 8679; [11] J.F. Bell III *et al.* (2000) *JGR 105,* 1721; [12] R.V. Morris *et al.* (2000) *JGR 105,* 1757; [13] M. Malin *et al.,* this volume; [14] H. McSween *et al.,* this volume; [15] R. Arvidson *et al.,* this volume; [16] R.V. Morris *et al.,* this volume; [17] M. Wolff *et al.,* this volume.