LARGE MULTISPECTRAL AND ALBEDO PANORAMAS ACQUIRED BY THE PANCAM INSTRUMENTS ON THE MARS EXPLORATION ROVERS *SPIRIT* AND *OPPORTUNITY*.

J.F. Bell III[1] (jfb8@cornell.edu), H.M. Arneson[1], W.H. Farrand[2], W. Goetz[3], A.G. Hayes[1], K. Herkenhoff[4], M.J. Johnson[1], J.R. Johnson[4], J. Joseph[1], K. Kinch[5], M.T. Lemmon[6], M.B. Madsen[3], E. McCartney[1], R.V. Morris[7], J. Proton[1], D. Savransky[1], F. Seelos[8], J. Soderblom[1], J.N. Sohl-Dickstein[1], R.J. Sullivan[1], M.J. Wolff[2], and the Athena Science Team, [1]Cornell University; [2]Space Science Institute; [2]Washington University, St. Louis; [3]University of Copenhagen, Denmark; [4]U.S. Geological Survey, Flagstaff; [5]Aarhus University, Denmark; [6]Texas A&M University; [7]NASA Johnson Space Center; [8]Washington University, St. Louis.

Introduction. The panoramic camera (Pancam) multispectral, stereoscopic imaging systems on the Mars Exploration Rovers *Spirit* and *Opportunity* [1] have acquired and downlinked more than 45,000 images (~35 Gbits of data) over more than 700 combined sols of operation on Mars as of early January 2005. A large subset of these images were acquired as part of 26 large multispectral and/or broadband "albedo" panoramas (15 on *Spirit*, 11 on *Opportunity*) covering large ranges of azimuth (12 spanning 360°) and designed to characterize major regional color and albedo characteristics of the landing sites and various points along both rover traverses.

Multispectral Panoramas. Table 1 provides a list of the large-scale Pancam multispectral panoramas acquired by both rovers as of *Spirit* sol 363 and *Opportunity* sol 342.

Table 1. Pancam Multispectral Pans as of 9 Jan. 05

Sols	Name	Az. Span	Filters [1] Left	Filters [1] Right
	Spirit			
3-5	Mission Success 1	360°	2,5,6	2,7
9	120° Survey	120°	2-7	1-7
6-10	Mission Success 2	360°	2,5,6	2,7
59-61	Legacy	360°	2,5,6	2,7
68,69	Bonneville	360°	2,5,6	2,7
80-85	Bonneville Interior	100°	2-7	1-7
91	Columbia Hills 1	70°	2-7	1-7
136-141	Santa Anita	360°	2,5,6	2,7
149	Columbia Hills 2	120°	2-7	1-7
213-223	Cahokia	360°	2,5,6	2,7
318-325	Thanksgiving	360°	2,5,6	2,7
329-330	Deck	360°	4,5,6	--
	Opportunity			
2,3	Mission Success	360°	2,5,6	2,7
17-26	Outcrop	160°	2,5,7	1,2,5,7
58,60	Eagle Crater	360°	2,5,6	2,6,7
96, 97	Endurance West	180°	2,5,6	2,6,7
117-123	Endurance South	360°	2,5,6	2,6,7
287-294	Burns Cliff	180°	2,5,7	1,2,6,7
322,323	Deck	360°	4,5,6	--

The primary objective of these large-scale multispectral imaging observations is to characterize the geologic context, topography, and gross color properties of unique and/or representative locations along each rover's traverse path, while minimizing the observation time and number of downlinked bits required to do that characterization.

Geologic characterization comes from imaging terrain and albedo features in the red filters (L2 or R2, 750 nm), or by effectively removing the effects of albedo variations by focusing on images in the blue filters (L6 or L7, 480 or 430 nm), because nearly all rock and soil materials on Mars have roughly the same (low) albedo at these wavelengths. Topographic models of each location can be derived by merging the left and right eye L2 and R2 images.

Overall visible wavelength color properties can be assessed by generating false color composites or approximate true color renderings [2] of each location using L2, L5, L6 (750, 530, 480 nm) or L2, L5, L7 (750, 530, 430 nm) RGB composites. These wavelengths provide the maximum amount of "wavelength leverage" for measuring parameters like spectral slope and the 530 nm "kink" often used to assess ferric iron crystallinity in laboratory, telescopic, and spacecraft data [3,4]. Similar simple characterization of the near-IR spectral slope and thus a measure of the relative strength of ferric vs. ferrous absorptions in materials in the scene [3,4], comes from ratios of the right eye R2 (750 nm) and R7 (1009 nm) images. For *Opportunity* panoramas, addition of the R6 (934 nm) filter to the nominal wavelength set provided the ability to use a simple but powerful metric–the R6/R7 ratio–to distinguish and map the distribution of hematite-rich concretions [5,6]. The additional data and time expense incurred by adding this filter to these large panoramas was more than offset by the significant increase in the ability to spectrally discriminate among the interesting and unique materials found at Meridiani Planum.

In the case of the rover deck panoramas, the primary goal was the derivation of scene "true color" (for dust assessment), so the L4, L5, and L6 filters (600, 530, 480 nm) were used because they have bandpasses closest to those of the human eye [1]. A simple L4, L5, L6 RGB composite generated from properly-calibrated images provides the simplest approximation to how color would be perceived by human eyes on Mars. A more rigorous and quantitative derivation of the true color is possible using any of the left eye filter combinations used in Table 1, though the most accurate derivation of the chromaticity of a scene imaged by the Pancams requires the use of all six of the cameras' left eye narrowband filters (L2 though L7) [2].

"Albedo" Panoramas. One of the Pancam filter wheel positions (Left eye, position 1: L1) was left empty to provide maximum sensitivity for low-light imaging and to provide the broadest possible spectral bandpass for the imaging system. The effective bandpass of L1 images is governed by the quantum efficiency of the Pancam CCDs and the spectral characteristics of the optics and was determined during calibration to be 739±338 nm [1]. The L1 images are calibrated to radiance factor (I/F) using near-simultaneous L1 images of the Pancam calibration target [1]. For parts of the scene that are observed at the same incidence angle as the cal target (*i.e.*, mostly flat-lying areas), this calibration method also effectively removes the diffuse illumination component coming from sky radiance that is also incident on the scene [7]. An estimated albedo can be derived by dividing the derived I/F values by the cosine of the solar incidence angle at the time of each observation. Pancam's L1 filter is only sensitive to about 40% of the solar radiance reflected from Mars measured in the 200 to 3000 nm wavelength range by instruments like the Viking Orbiter Infrared Thermal Mapper (IRTM) or Mars Global Surveyor Thermal Emission Spectrometer (TES) albedo channel. Virtually all of the radiance not measured by Pancam is in the 1000 to 3000 nm region because of the very low blue to UV reflectivity of the martian surface. However, and fortuitously, since the martian reflectance spectrum is generally flat in the 1000 to 3000 nm region not measurable by Pancam [8], an albedo estimated from a Pancam L1 filter observation that is effectively cut off near 1000 nm should still be comparable, for spectrally-typical Mars terrains, to an albedo estimated from IRTM or TES measurements that sample the radiance out to 3000 nm.

Table 2 provides a list of the large-scale Pancam albedo panoramas acquired by both rovers as of *Spirit* sol 363 and *Opportunity* sol 342. We derived estimated albedos from these observations for direct comparisons to previous orbital and telescopic remote sensing albedo estimates.

At the *Spirit* landing site in Gusev crater, we found the albedo to be 0.25±0.05, which is comparable to the TES bolometric albedo of the Viking Lander 1 site (0.26±0.05), slightly higher than the albedo of the Viking Lander 2 (0.23±0.01) or Mars Pathfinder (0.22±0.01) sites, but within the uncertainties of previous orbital and telescopic estimates of the albedo of the Gusev landing error ellipse (~0.23; [9]). Observed albedo variations ranged from 0.20±0.02 within darker wind streaks, to 0.30±0.02 within hollows and Bonneville crater ejecta. These albedo extremes are consistent with the lowest (~0.19) and highest (~0.26) albedos measured by TES within the Gusev landing error ellipse [9].

Table 2. Pancam "Albedo" Pans as of 9 Jan. 05

Sols	Name	Az. Span	Filter [1]
Spirit			
46	MGS Albedo	180°	L1
136-141	Santa Anita	360°	L1
356	Columbia Hills	250°	L1
Opportunity			
22	MGS Albedo	360°	L1
68	Plains Albedo	90°	L1
309	Endurance Dunes	70°	L1
309	Endurance Wall	110°	L1

At the *Opportunity* landing site in Meridiani Planum, the albedo of the dark deposits within Eagle crater is estimated to be 0.14±0.01, which is comparable to the average albedo of the plains outside of Eagle crater, estimated to be 0.12±0.01. These albedos are comparable to the IRTM (0.14±0.06) and TES (0.12±0.03) bolometric albedos of the Opportunity landing site pixel, which is in a lower-than-average albedo portion of the landing ellipse [9]. The bright outcrop materials within Eagle crater have an average albedo of 0.25±0.06, and brighter wind streak deposits in Eagle crater, just outside of the rim of Eagle crater, and in the surrounding plains, exhibit albedo values between 0.19 and 0.29, which is a range consistent with the albedo of bright dust.

Additional quantitative analyses of the Pancam multispectral and albedo panorama data from *Spirit* and *Opportunity* are ongoing, and it is likely that many more panoramas will be acquired before the missions end.

References: [1] Bell III, J.F. *et al.* (2003) *JGR, 108*, 10.1029/2003JE002070. [2] D. Savransky and J.F. Bell III, *EOS, Trans. AGU*, Abstract P21A-0197, 2004. [3] Morris, R.V. *et al.* (2000) *JGR*, *105*, 1757-1817. [4] Bell III, J.F. *et al.* (2000) *JGR, 105*, 1721-1755. [5] Soderblom, L.A. *et al.* (2004) *Science, 306,* 1723-1726. [6] Bell III, J.F. *et al.* (2004) *Science, 306,* 1703-1709. [7] Reid, R.J. *et al.*, (1999) *JGR, 104,* 8907-8926. [8] Mustard, J.F. and J.F. Bell III (1994) *GRL, 21,* 353-356. [9] M.P. Golombek *et al.* (2003) *JGR. 108*, 10.1029/2003JE002074.