Albedo and Multispectral Properties of Rocks and Soils at Gusev and Meridiani from the Mars Exploration Rover Pancam Imaging Systems

Presented May 25, 2005 at the American Geophysical Union Spring Meeting, New Orleans, LA

Jim Bell (Cornell University) Representing the Athena Science Team
Outline

• Gusev and Meridiani Color and Albedo
• Visible to Near-IR Spectral Units
  – Rocks, clasts, soil, dust, and other materials
  – Comparison with previous measurements
  – Mineralogic implications
• Update on Latest Measurements...
Pancam Summary

- Two CCD cameras per rover
- Stereo separation 30 cm
- 1024 × 1024 pixel images
- Focal length 42 mm, f/20
- Resolution = 0.28 mrad/pixel
- Field of view: 16° × 16°
- 8 filters/eye, 400-1050 nm
- Onboard calibration target
- Wavelet image compression
- Some onboard image processing

Bell et al., JGR, Dec. 2003
Pancam Data Sets

- **MER-A “Spirit”**
  - 33,248 images as of Sol 493 (3.20 GBytes of raw data)
  - Eight 360° color panoramas acquired
  - About a dozen more very large color panoramas
  - Hundreds of 11-color multispectral spots

- **MER-B “Opportunity”**
  - 31,624 images as of Sol 473 (2.93 GBytes of raw data)
  - Five 360° color panoramas acquired
  - About ten more very large color panoramas
  - Hundreds of 11-color multispectral spots
Albedo: Gusev and Meridiani
### Pancam "Albedo" Panoramas as of 23 May 05

<table>
<thead>
<tr>
<th>Sol</th>
<th>Name</th>
<th>Az. Span</th>
<th>Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Pancam</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>MGS Albedo</td>
<td>180°</td>
<td>L1</td>
</tr>
<tr>
<td>136-141</td>
<td>Santa Anita</td>
<td>360°</td>
<td>L1</td>
</tr>
<tr>
<td>356</td>
<td>Columbia Hills</td>
<td>250°</td>
<td>L1</td>
</tr>
<tr>
<td></td>
<td><strong>Opportunity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>MGS Albedo</td>
<td>360°</td>
<td>L1</td>
</tr>
<tr>
<td>68</td>
<td>Plains Albedo</td>
<td>90°</td>
<td>L1</td>
</tr>
<tr>
<td>309</td>
<td>Endurance Dunes</td>
<td>70°</td>
<td>L1</td>
</tr>
<tr>
<td>309</td>
<td>Endurance Wall</td>
<td>110°</td>
<td>L1</td>
</tr>
<tr>
<td>348</td>
<td>Plains Albedo</td>
<td>360°</td>
<td>L1</td>
</tr>
<tr>
<td>363</td>
<td>Plains Albedo</td>
<td>360°</td>
<td>L1</td>
</tr>
<tr>
<td>374</td>
<td>Plains Albedo</td>
<td>360°</td>
<td>L1</td>
</tr>
<tr>
<td>409</td>
<td>Plains Albedo</td>
<td>360°</td>
<td>L1R1267</td>
</tr>
<tr>
<td>411</td>
<td>Plains Albedo</td>
<td>360°</td>
<td>L1</td>
</tr>
<tr>
<td>418</td>
<td>Plains Albedo</td>
<td>360°</td>
<td>L1R1267</td>
</tr>
<tr>
<td>427</td>
<td>Plains Albedo</td>
<td>360°</td>
<td>L1</td>
</tr>
<tr>
<td>429</td>
<td>Plains Albedo</td>
<td>360°</td>
<td>L1</td>
</tr>
<tr>
<td>435</td>
<td>Plains Albedo</td>
<td>360°</td>
<td>L1R1267</td>
</tr>
<tr>
<td>442</td>
<td>Plains Albedo</td>
<td>360°</td>
<td>L1R1267</td>
</tr>
<tr>
<td>454</td>
<td>Plains Albedo</td>
<td>360°</td>
<td>L1R1267</td>
</tr>
</tbody>
</table>

“Albedo” is estimated by dividing the I/F determined from observations calibrated using the onboard calibration target by the cosine of the solar elevation angle at the time of each observation. This albedo estimate should be comparable to bolometric Lambert albedo values derived from orbital observations.
Gusev Albedo

Average: 0.25 ± 0.05

TES Avg: 0.23 ± 0.03

Dark Streak Average: 0.20 ± 0.02

Bright Soil Average: 0.30 ± 0.02

Sol 66

Jim Bell (Cornell University)

2005 AGU Spring Meeting, New Orleans, LA

Bell et al., Science, 305, 800 (2004)
Meridiani Albedo

Average Plains: $0.12 \pm 0.01$
TES Landing Pixel: $0.12 \pm 0.03$
Bright Outcrop Average: $0.25 \pm 0.06$
Bright Plains Wind Streaks: 0.19 to 0.29


2005 AGU Spring Meeting, New Orleans, LA
Opportunity traversing south...
Meridiani plains albedo: Sol 442 (Apr. 22)

Average albedo of plains: 0.158±0.016

Looking south...

Average albedo: 0.157±0.014

Looking north...

Average albedo: 0.157±0.013 (not including tracks)

Jim Bell (Cornell University)

2005 AGU Spring Meeting, New Orleans, LA
Meridiani plains albedo: Sol 454 (May 4)

Average albedo of plains, ~100 m farther south: 0.156±0.016

Average albedo: 0.155±0.012

Average albedo: 0.157±0.014 (not including tracks)

Jim Bell (Cornell University)

2005 AGU Spring Meeting, New Orleans, LA
Multispectral Properties at Gusev
<table>
<thead>
<tr>
<th>Sol</th>
<th>Name</th>
<th>Az. Span</th>
<th>Filters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Left</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Right</td>
</tr>
<tr>
<td>2</td>
<td>Postcard</td>
<td>90°</td>
<td>2,5,6</td>
</tr>
<tr>
<td>3-5</td>
<td>Mission Success 1</td>
<td>360°</td>
<td>2,5,6</td>
</tr>
<tr>
<td>5</td>
<td>Postcard</td>
<td>110°</td>
<td>2,5,6</td>
</tr>
<tr>
<td>9</td>
<td>120° Survey</td>
<td>120°</td>
<td>2-7</td>
</tr>
<tr>
<td>6-10</td>
<td>Mission Success 2</td>
<td>360°</td>
<td>2,5,6</td>
</tr>
<tr>
<td>59-61</td>
<td>Legacy</td>
<td>360°</td>
<td>2,5,6</td>
</tr>
<tr>
<td>68-69</td>
<td>Bonneville</td>
<td>360°</td>
<td>2,5,6</td>
</tr>
<tr>
<td>80-85</td>
<td>Bonneville Interior</td>
<td>100°</td>
<td>2-7</td>
</tr>
<tr>
<td>91</td>
<td>Columbia Hills 1</td>
<td>70°</td>
<td>2-7</td>
</tr>
<tr>
<td>136-141</td>
<td>Santa Anita</td>
<td>360°</td>
<td>2,5,6</td>
</tr>
<tr>
<td>149</td>
<td>Columbia Hills 2</td>
<td>120°</td>
<td>2-7</td>
</tr>
<tr>
<td>213-223</td>
<td>Cahokia</td>
<td>360°</td>
<td>2,5,6</td>
</tr>
<tr>
<td>239, 261</td>
<td>Change Detection</td>
<td>120°</td>
<td>2,5,7</td>
</tr>
<tr>
<td>241</td>
<td>Tikal Mosaic</td>
<td>60°</td>
<td>2,5,7</td>
</tr>
<tr>
<td>318-325</td>
<td>Thanksgiving</td>
<td>360°</td>
<td>2,5,6</td>
</tr>
<tr>
<td>329-330</td>
<td>Deck</td>
<td>360°</td>
<td>4,5,6</td>
</tr>
<tr>
<td>388</td>
<td>Alligator Outcrop</td>
<td>110°</td>
<td>2,5,7</td>
</tr>
<tr>
<td>410-413</td>
<td>Lookout</td>
<td>360°</td>
<td>2,5,6</td>
</tr>
<tr>
<td>432</td>
<td>Deck</td>
<td>360°</td>
<td>4,5,6</td>
</tr>
<tr>
<td>464-465</td>
<td>Methuselah Outcrop</td>
<td>180°</td>
<td>2,5,7</td>
</tr>
<tr>
<td>477</td>
<td>Jibsheet Outcrop</td>
<td>110°</td>
<td>2,5,7</td>
</tr>
</tbody>
</table>
Spectral diversity of Gusev rocks and soils

sol 332 “Wishbone”
sol 293 “Uchben”
sol 220 “Toltecs”
sol 492 “Larry’s Outcrop”
Gusev Spectral Diversity

A

B

C

D

E

F

Jim Bell (Cornell University)
Visible to Near-IR Spectral Classes

- Wide range of I/F values
- Everything has a strong ferric absorption edge (except RAT holes)
- Soil spectra “dust-like”
  - nanophase ferric iron dominates
  - minor “crystalline” ferric component
- Dark rock spectra have a negative near-IR slope and a well-defined ferrous band
  - “basaltic” signature
  - consistent with px or ol

Bell et al., Science, 305, 800 (2004)
Visible to Near-IR Spectral Classes

- Wide range of I/F values
- Everything has a strong ferric absorption edge (except RAT holes)
- Soil spectra “dust-like”
  - nanophase ferric iron dominates
  - minor “crystalline” ferric component
- Dark rock spectra have a negative near-IR slope and a well-defined ferrous band
  - “basaltic” signature
  - consistent with px or ol
- Consistent with telescopic and Pathfinder spectra
- Except for “white” places...

Bell et al., Science, 305, 800 (2004)
Mustard & Bell, GRL (1994); Bell et al., JGR (2000)
High Sulfur deposits!

Sol 381A
“Peace”

Sol 431A
“Paso Robles”

Sol 400A
“Paso Robles”

10 cm
Spectra reveal much weaker ferric absorption signature...

J. Johnson et al., 2005

Jim Bell (Cornell University) 2005 AGU Spring Meeting, New Orleans, LA
...as well as higher reflectance and a reflectance peak near 673 nm.

J. Johnson et al., 2005

2005 AGU Spring Meeting, New Orleans, LA
Pancam spectral parameters indicate general consistency with Fe,S-rich Mars analog materials studied by Morris et al. (2000) and others, but need more information to choose among possible sulfates...
Multispectral Properties at Meridiani
### Opportunity Multispectral Pans as of 23 May 05

<table>
<thead>
<tr>
<th>Sols</th>
<th>Name</th>
<th>Az. Span</th>
<th>Filters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Postcard</td>
<td>110°</td>
<td>2,5,6, --</td>
</tr>
<tr>
<td>2,3</td>
<td>Mission Success</td>
<td>360°</td>
<td>2,5,6, 2,7</td>
</tr>
<tr>
<td>17-26</td>
<td>Outcrop</td>
<td>160°</td>
<td>2,5,7, 1,2,5,7</td>
</tr>
<tr>
<td>58,60</td>
<td>Eagle Crater</td>
<td>360°</td>
<td>2,5,6, 2,6,7</td>
</tr>
<tr>
<td>96,97</td>
<td>Endurance West</td>
<td>180°</td>
<td>2,5,6, 2,6,7</td>
</tr>
<tr>
<td>117-123</td>
<td>Endurance South</td>
<td>360°</td>
<td>2,5,6, 2,6,7</td>
</tr>
<tr>
<td>287-294</td>
<td>Burns Cliff</td>
<td>180°</td>
<td>2,5,7, 1,2,6,7</td>
</tr>
<tr>
<td>322,323</td>
<td>Deck</td>
<td>360°</td>
<td>4,5,6, --</td>
</tr>
<tr>
<td>330</td>
<td>Heat Shield Impact</td>
<td>95°</td>
<td>2-7, 1-7,</td>
</tr>
<tr>
<td>393</td>
<td>Naturaliste Craters</td>
<td>140°</td>
<td>4,5,6, --</td>
</tr>
<tr>
<td>400</td>
<td>Vostok Crater</td>
<td>160°</td>
<td>2,5,7, 1</td>
</tr>
<tr>
<td>422</td>
<td>Viking Crater</td>
<td>150°</td>
<td>2,5,7, 1</td>
</tr>
<tr>
<td>456-464</td>
<td>Rub al Khali Plains</td>
<td>360°</td>
<td>2,5,6, 2,6,7</td>
</tr>
</tbody>
</table>
Meridiani Spectral Units

*Opportunity:* Sol 20
False color composite
Scene is ~ 50 cm wide

2005 AGU Spring Meeting, New Orleans, LA
Meridiani Spectral Units

Opportunity: Sol 68 13:00
False color composite
Scene is ~ 40 cm wide

2005 AGU Spring Meeting, New Orleans, LA
Visible to Near-IR Spectral Classes

- Wide range of I/F values in “dust” and “sand”

Visible to Near-IR Spectral Classes

- Wide range of I/F values in “dust” and “sand”
- These simple classes are ~ consistent with telescopic and Pathfinder spectra

Mustard & Bell, GRL (1994); Bell et al., JGR (2000)
Visible to Near-IR Spectral Classes

- Wide range of I/F values in “dust” and “sand”
- These simple classes are ~ consistent with telescopic and Pathfinder spectra
- But there are many other unique spectral classes!

Mustard & Bell, GRL (1994); Bell et al., JGR (2000)
Visible to Near-IR Spectral Classes

- Wide range of I/F values in “dust” and “sand”
- Everything has a strong ferric absorption edge (except RAT holes)
- But there are many other unique spectral classes!
  
  - Nanophase ferric (?) outcrop
  - Crystalline ferric blueberries
  - Hematite-rich (?) plains
  - Olivine-pyroxene rich rock
  - “Gray” (Hm?) cobbles

A few words about...

**Calibration**

- Pancam cal target observations
  - Provides a quick estimate of reflectance
  - Precision $\leq 3\%$; Accuracy $\sim 10-15\%$
- But targets are getting dusty...
  - Our model uses lab data and the sweep magnet’s “clean spot” to estimate a dust correction for deriving I/F

**Spirit Pancam calibration target images**

<table>
<thead>
<tr>
<th>Sol 2A</th>
<th>Sol 55A</th>
<th>Sol 150A</th>
<th>Sol 302A</th>
</tr>
</thead>
</table>

Jim Bell (Cornell University)

2005 AGU Spring Meeting, New Orleans, LA
But the dust has sometimes been “cleaned” by the wind...

<table>
<thead>
<tr>
<th>Spirit</th>
<th>Sol 5</th>
<th>Sol 102</th>
<th>Sol 240</th>
<th>Sol 328</th>
<th>Sol 416</th>
<th>Sol 417</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
<td><img src="image7.png" alt="Image" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Sol 4</th>
<th>Sol 101</th>
<th>Sol 151</th>
<th>Sol 265</th>
<th>Sol 314</th>
<th>Sol 395</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image8.png" alt="Image" /></td>
<td><img src="image9.png" alt="Image" /></td>
<td><img src="image10.png" alt="Image" /></td>
<td><img src="image11.png" alt="Image" /></td>
<td><img src="image12.png" alt="Image" /></td>
<td><img src="image13.png" alt="Image" /></td>
<td><img src="image14.png" alt="Image" /></td>
</tr>
</tbody>
</table>

more.... more... more... more... less! more.... more... less... more... more...
Spirit Pancam temperature history...

A Sol: 1  50        100           200              300             400           500

Jim Bell (Cornell University)

2005 AGU Spring Meeting, New Orleans, LA
Opportunity Pancam temperature history...
Summary

• There is a wide variety of 400 to 1100 nm visible color and near-IR spectral variation in the rocks and soils at Gusev and Meridiani.

• Two spectral classes at both sites are consistent with previous telescopic and MPF/IMP data:
  – A bright “global” dust component in all soils
  – A dark “global basaltic” sand component

• Other unique spectral classes identified, and can be related to variations in Fe, S mineralogy.

• Lots of calibrated radiance data have been released to the PDS, much more to come...
MER Data Sets

- **MER-A “Spirit”**
  - As of sol 493 (May 24)
  - 47,949 total images
  - 45.0 total Gbits (5.6 GB)
  - 33,248 Pancam images
  - 2,509 MI Images
  - millions of MiniTES spectra
  - 85+ APXS rock/soil spectra
  - 83+ MB rock/soil spectra
  - 14+ RAT holes (48 brushes)
  - Odometry as of 5/24: 4368 m

- **MER-B “Opportunity”**
  - As of sol 473 (May 24)
  - 44,047 total images
  - 42.8 total Gbits (5.4 GB)
  - 31,624 Pancam images
  - 2,706 MI Images
  - millions of MiniTES spectra
  - 71+ APXS rock/soil spectra
  - 91+ MB rock/soil spectra
  - 22+ RAT holes (9 brushes)
  - Odometry as of 5/24: 5346 m