Existing Lunar Datasets

Workshop on Lunar Knowledge
Requirements for Human Exploration
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Overview

• Many *diverse* datasets from early telescopic to Lunar Prospector and new ground based measures, SMART 1 and Lunar A and Selene
• Nearly global geophysical measures at low resolution (topography, gravity)
• Global Elemental maps (30-100 km/p)
• Global multispectral imaging moderate resolution with derived elemental and mineralogic maps, poor control
• Select high resolution orbital imaging to sub-meter
• Surface EVA to sub-mm imaging
• Spotty data on 3-D nature of the regolith

**What is Missing?**

• *Uniform global* geodetic control network (lat, lon, radii)
• *Uniform global* high resolution mineralogic/compositional data
• *Uniform global* high resolution morphology
• *Uniform global* regolith characterization
• Knowledge of interior of polar shadowed craters
Existing Lunar Remote Sensing Datasets

- Earth Based Telescopes
- Ranger
- Surveyor
- Lunar Orbiter
- Apollo Photography
  - handheld
  - automated
- Apollo Laser Altimetry
- Apollo Elemental
- Soviet Data

- Earth Based Radar
- Clementine
  - Imaging, topography
- Lunar Prospector
  - Elemental maps
- Gravity
- Global Control Network
- Ongoing/planned missions
Earth Based Telescopes

- Atlas and Gazetteer of the Near Side of the Moon (NASA SP-241)
- Rectified Lunar Atlas
- Consolidated Lunar Atlas (now digital LPI website)
- Many others…

Whitaker color difference photo, 1966, 1972
Ranger 1964-65

Nested descent imaging up to impact, km to meter resolution, very limited coverage

- Ranger 7 Mare Cognitum
- Ranger 8 Mare Tranquillitatis
- Ranger 9 Alphonsus Crater

Status: Good Selection of scans at NSSDC webpage, high quality prints in many libraries
Surveyor 1966-68
Surface Operations

meter to mm surface imaging

- Surveyor 1 Flamsteed P
  - 11,000 images
- Surveyor 3 Oceanus Procellarum
  - 6300 images, sampling arm
- Surveyor 5 Mare Tranquillitatis
  - 19,000 images, alpha backscatter
- Surveyor 6 Sinus Medii
  - 29,000 images, alpha backscatter
- Surveyor 7 Tycho Crater
  - 21,000 images, alpha backscatter

Surveyor 3 Visited by Apollo 12

Status: Photographic prints and mosaics available at some RPIFS
Compositional analyses in literature
Lunar Orbiter 1966-67

- Lunar Orbiter I, II, III
  - high resolution mapping of equatorial Apollo targets (down to 1 m/p)
- Lunar Orbiter IV
  - polar orbits for synoptic mapping (60-600 m/p)
- Lunar Orbiter 5
  - high resolution “science” targets (down to 1 m/p)
- All measured lunar gravity field nearside and a bit of the farside

Best existing global BW morphology dataset ~300 m/p
Lunar Orbiter Status

• USGS Scan Project (from negatives)
  – Completed synoptic IV and V frames to make global map
  – started scanning selection of highest resolution frames - does community want/need all frames scanned?
  – controlling to Clementine basemap to reconstruct geometry (danger)
  – web-based distribution, archive to PDS
• LPI scans of Bowker and Hughes *Lunar Orbiter Photographic Atlas of the Moon*
• Northwestern University/LPI scans of LO II, III, IV H Frames from prints available from NU CPS website
Lunar Orbiter High Resolution Coverage

- ~1m / pixel covers ~1% of Moon
- ~10 m/pixel covers ~12% of Moon
- Inc angle typically 70°
- Quality varies from stunning to muddy
- Geometric and photometric fidelity less than optimal

800 m wide
Apollo Photography 1968-72

- Handheld 70-mm
  - 10,000 Color
  - 10,000 BW
  - Orbit, surface
- Metric Camera (15, 16, 17)
  - BW, 127 x 127 mm (5” x 5”)
- Panoramic Camera
  - BW, 127 mm x 1 m
- 35-mm, Ap 14 Hycon, surface stereo…

Status: Only dupes are easily available, of varying quality.
Apollo 70 mm Status

- Copy negatives at RPIFs generally in poor condition
- Originals in pristine condition, but inaccessible
- Resolutions of cm to km
- 10,000 BW; 10,000 Color

Recent scan from flight positive

Scanning to digital format in planning stage NASA, JSC, NU CPS
Metric Camera Coverage

Much overlap for stereo, incidence angle ranges from 90° to near 0°, simultaneous laser point. ~10,000 negatives. Pilot scan project in planning stage.
Panorama Camera Coverage

Much overlap for stereo, incidence angle ranges from 90° to near 0°
Soviet Missions

• Luna Missions
  – Landers, rovers, sample return missions
  – 1966-76
• Must be lots of image data?
• Appears in books
• NSSDC has “poor quality” reproductions

Status: Quality prints generally unavailable to US scientists?
Earth Based Radar

Nearside

- 3 cm to 70 cm
  - polarized component, morphology
  - depolarized component, surface roughness
  - 30 to 300 m/pixel
- Topography
  - interferometry
  - 150 m/p, 50 m vertical
- Could map whole nearside
- Data should be archived with PDS, investigators willing

Status: Only available on request from PIs
Mariner 10 / Galileo

- Mariner 10 1973 BW 1 km mosaic on way to Mercury, very low resolution color, available on NU CPS webpage

Galileo two flybys in 1990 and 1992 returned CCD multispectral imaging for ~60% of Moon at 1-20 km/p, Mosaics available by special request from USGS, mosaics should be archived at PDS (if not)
Clementine 1994

- **UVVIS (CCD)**
  - 100-200 m/p global
  - 5 filters (415-1000 nm)
- **NIR (InSb)**
  - 160-320 m/p global
  - 6 filters (1100-2800 nm)
- **HIRES (CCD)**
  - 25-50 m/p (effective)
  - 4 filters (415-750 nm)
  - BW poles, selected color strips
- **LWIR (HgCdTe)**
  - 200-400 m/p global
  - broadband (8000-9500 nm)
- **LIDAR Ranging** (2.5° spatial, 100 m vertical, 65S to 65N)
Clementine Products

- EDRs archived with PDS
- UVVIS 5 band global mosaic PDS
- NIR 6 band global mosaic PDS
- HIRES BW mosaics MSSS to PDS
- HIRES BW and color mosaics NU CPS webpage
- LIDAR based topography and gravity ± 65° of equator (2.5° res) at PDS, radii of poles not well constrained
- Derived Maps (FeO, TiO, maturity, mineralogy) from investigators

Derived maps excellent start on mineralogic/composition cataloging
Lunar Prospector 1998-99

- Gamma Ray Spectrometer
  - 5° maps (150 km) O, Si, Ti, Al, Fe, Mg, Ca, U, K, Th

- Neutron Spectrometer
  - 2° maps (60 km) Sm, Ti, K, H, Th,

- High resolution low orbit
  - 0.5° maps (15 km) Th, Fe, H

Initial Elemental Maps at PDS, improved versions from investigators
Gravity

- Clementine, LO 1-5, Apollo 15, 16 subsatellite (Lemoine et al, circa 2000)
- Gravity characterized to degree and order 70
- Much of farside knowledge must be poorer than nearside due to tracking loss Clementine and LO (120° to 240° long., -45° to 45° lat.)

Clementine based gravity map
Current Lunar Control Network

- 43,000 Clementine 750 nm images (postage stamp problem)
- 265,000 match-points
- Ground truth from “Apollo zone”, all of farside and much of nearside floats
- No topography used, assumed spherical Moon of 1737.4 km (results in scale errors up to 4%)
- Spacecraft position fairly well known
  - Doppler tracking (until occulted on farside)
  - Gravity models

What is accuracy of the control network? Precision of fit 100 m.
Control Network Accuracy?

- Recently completed global stereo based topo map (Cook et al) controlled to LIDAR elevations (poor at poles)
- Used original archived SPICE pointing files (not USGS/Rand control net)
- Overlaid the topo with USGS/Rand 750 nm basemap and found impossibly large offsets (>12 km)

Clementine stereo topo on 750 nm basemap
750nm Basemap Geometric Accuracy?

\[ \Delta \] Camera Pointing Map

Offset Map: Is this a map of absolute accuracy (lat/lon)?
What is Missing?

- Global uniform high resolution Geodetic Model
  - topography
  - gravity
  - position
- High-Res, High-Fidelity (Color) Mineralogic Mapping
- Very high resolution (sub-meter) imaging outside of Apollo targets
- Polar Shadowed crater interiors? What is in there?
- Uniform, global regolith structure characterization
<table>
<thead>
<tr>
<th>Geodetic Model</th>
<th>Current State</th>
<th>Proposed Measurement</th>
<th>Rationale</th>
<th>SMART1/Selene/Lunar-A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>~10 km x and y, 100 m z</td>
<td>5-10 m x and y, 1 m z</td>
<td>LSI, ASR, ESB</td>
<td>Selene Laser Altimeter, Stereo Terrain camera, tracking subsatellite</td>
</tr>
<tr>
<td>Polar Shadowed crater interiors, composition, morphology</td>
<td>100 m/p morphology for parts visible from Earth, radii ±1-4 km</td>
<td>Locate positions (x,y,z) of H deposits, unambiguous composition</td>
<td>LSI, RS, ESB</td>
<td>Lunar A seismometer, Heat flow, Selene Radar Sounder</td>
</tr>
<tr>
<td>Regolith 3-D characterization</td>
<td>Scattered local measures</td>
<td>10 m deep, 100 m scale</td>
<td>LSI, RS, ASR, ESB</td>
<td>Lunar A seismometer, Heat flow, Selene Radar Sounder</td>
</tr>
<tr>
<td>Hi Res Morphology</td>
<td>1 m/p 15% with varying inc 10 m 20%</td>
<td>Sub-meter locally, 10 m global</td>
<td>LSI, RS, ASR, ESB</td>
<td>Lunar A seismometer, Heat flow, Selene Radar Sounder</td>
</tr>
<tr>
<td>Hi Res / Hi SNR Mineralogic mapping</td>
<td>500 m/p globally (with minimum bandpasses)</td>
<td>10 m/p locally, 100 m/p globally, better spectral coverage</td>
<td>LSI, RS, ASR, ESB</td>
<td>Selene 9 band VIS-NIR 20-60 m/p, Spectrometer 500 m/p</td>
</tr>
</tbody>
</table>

LSI = Landing Site Identification, RS = Resource Identification, ASR = Applied Science and Research applicable to Moon to Mars, ESB = Engineering Safety and Boundary conditions,
Selene

- X-Ray
- Gamma-Ray
- Multiband Imager
- Spectral Profiler
- Terrain Camera (Stereo)
- Laser Altimeter
- Sounder
- Gravity subsatellite (2)
- Magnetometer
- Plasma experiments

Launch in 2005
Lunar A Japan

- Two penetrators
  - Seismometer
  - Heat Flow
- BW Camera on Orbiter (20 m/p)
- Launch 2004
SMART 1 ESA

- X-Ray (Fe, Mg, Si, Al)
- SIR - IR Spectrometer 340 - 2000 m, 940-2400 nm
- AMIE - Camera VIS (450, 750, 950 nm) 27-162 m
Web Resources

  - NU CPS: http://cps.earth.northwestern.edu/LO/index.html
  - LPI - http://www.lpi.usra.edu/research/apollo/
  - NU CPS - http://cps.earth.northwestern.edu/MOON/DOCUMENTS/
  - USGS NIR Mosaics - http://astrogeology.usgs.gov/Projects/ClementineNIR/
Web Resources

Current / Future Missions

• SMART 1 ESA - [http://sci.esa.int/science-e/www/area/index.cfm?fareaid=10](http://sci.esa.int/science-e/www/area/index.cfm?fareaid=10)


• 2005 - Selene Japan -

It appears the Moon is no longer made of American cheese!
Other Resources

- Ranger: JPL Tech. Reports, Library and RPIF prints
- Surveyor: NASA SPs 146, 163, 166, 173
- Apollo: Apollo Over the Moon (NASA SP-362)