Analysis of Terrain Mapping Camera (TMC) data sets of Chandrayaan-1 mission

STRUCTURE

Part: 1
- Browsing of Terrain Mapping Camera (TMC), HysI data sets
  - Polar data sets: TMC-LEVEL-1/DEM
  - Equatorial data sets: TMC-LEVEL-1/DEM

Part: 2
- Loading Global data sets of LRO: LOLA & Wide Angle Camera (WAC) as basemaps
- Loading of Moon Nomenclature
- Loading of TMC data set in GIS Software
- Loading of TMC data sets in ERDAS software
- Mapping of various morphological features using TMC data sets
- Brief overview of surface age determination of geological units of Lunar surface using Crater Size Frequency Size Distribution (CSFD)
Indian Space Science Data Centre (ISSDC) is the primary data center for the payload data archives of Indian Space Science Missions.

Contact E-mail: issdc@istrac.gov.in
Current Chandrayaan-1 data sets in this release are Peer Reviewed. The TMC and HySI data sets are based on the latest version of SPICE generated for the full mission except for the period from 14th Nov 2008 to 02nd Dec. 2008.

The accuracy of orbit information provided as navigation kernels can vary between 1-20 km. However, user can identify his area of interest on the browse with accuracy better than 1 km (due to the improved corners) for TMC and HySI. But in some cases of HySI it can go up to 20 km. Data losses can be present in a few products, wherein the position of data losses can vary in different bands of HySI. Saturation can be observed in few orbits of HySI. The number of Level-1b HySI products will not match with the number of Level-1a, due to the issues of mis-registration of bands. In some cases of the existing Level-1b products, mis-registration may exist between some bands.
TMC LEVEL-1 North Pole coverage
Base map Preparation in ARC GIS software

1) Loading of global LOLA topography data using Add Data button
   (for Seamless compatibility over various data source/Base map)
Adding Legend to map
Adding Grid lines and annotations to map

Create a graticule
## Name of Common Lunar landforms

<table>
<thead>
<tr>
<th>Latin name</th>
<th>Common name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mare (maria)---------------------</td>
<td>Sea</td>
<td>Dark, smooth plains.</td>
</tr>
<tr>
<td>Lacus, palus, sinus---------------</td>
<td>Highlands, uplands, continents.</td>
<td>Small mare. Rugged, relatively bright (high albedo) terrain.</td>
</tr>
<tr>
<td>Terra (terrae)</td>
<td>Mount, mountain(s)</td>
<td>High massif(s), generally forming arcuate ranges.</td>
</tr>
<tr>
<td>Promontorium</td>
<td>Promontory</td>
<td>Mountains partly enclosed by mare.</td>
</tr>
<tr>
<td>Rupes</td>
<td>Scarp</td>
<td>Fault in mare or high arcuate scarp in terra.</td>
</tr>
<tr>
<td>Dorsum (dorsa)</td>
<td>Mare ridge, wrinkle ridge</td>
<td>Narrow ridge, mostly in mare.</td>
</tr>
<tr>
<td>Rima (rimae)</td>
<td>Rille</td>
<td>Narrow, elongate depression (sinuous, arcuate, or straight).</td>
</tr>
<tr>
<td>Vallis (valles)</td>
<td>Valley</td>
<td>Wide, elongate depression, commonly consisting of inconspicuous craters.</td>
</tr>
<tr>
<td>Catena (catenae)</td>
<td>Chain</td>
<td>Chain of distinct craters.</td>
</tr>
<tr>
<td></td>
<td>Crater</td>
<td>Circular or subcircular depression, generally bounded by a raised rim.</td>
</tr>
<tr>
<td></td>
<td>Basin, ringed basin</td>
<td>Large craterlike depression containing one or more rings in addition to a rim.</td>
</tr>
</tbody>
</table>
Adding of Moon nomenclature and LRO-WAC image
Surface Morphology and Physiography

- Crater dominate all other landforms
  - Range in size from micro to mega meters
  - Shape and form change with increasing size (bowl shaped to central peaks to multiple rings)
- Maria are flat - lying to rolling plains.

- Few minor Landforms
  - Domes and cones
  - Faults and Graben
  - Other miscellaneous features
Impact craters

- Any depression, natural or manmade, resulting from the high velocity impact of a projectile with larger body.

- Approximately circular depression in the surface of a planet, moon or other solid body in the Solar System, formed by the hyper-velocity impact of a smaller body with the surface.

- Impact craters typically have raised rims, and they range from small, simple, bowl-shaped depressions to large, complex, multi-ringed impact basins.

Dependence of morphology with size

- Simple craters
- Complex craters
- Proto basins
- Two ring basins
- Multi ring basins

Dependence of morphology with age

- Fresh craters
- Topographic elements disappear with time
- Ancient (ghost)craters
**Secondary craters**

Secondary craters are impact craters formed by the ejecta that was thrown out of a larger crater. They sometimes form radial crater chains.

*Chain of secondary craters*

Secondary craters, produced by ejecta from larger primary impact craters, often form chains or clusters.
Lunar geological time scale

lunar geologic timescale is largely divided in time on the basis of prominent basin-forming impact events, such as Nectaris, Imbrium, and Orientale.

Lunar Geological time scale

- Copernican (< 1 Ga)
- Erasthenian (3.3 to 1 Ga)
- Imbrian (3.85 to 3.3 Ga)
- Nectarian (3.92 to 3.85 Ga)
- Pre-Nectarian (> 3.92 Ga)
Wrinkle ridge

- **Wrinkle ridges** are features created by compressive tectonic forces within the maria.
- These features are low, sinuous *ridges* formed on the mare surface that can extend for up to several hundred kilometers.

- These features represent buckling of the surface and form long ridges across parts of the maria.

- Some of these ridges may outline buried craters or other features beneath the mare.
- A prime example of such an outlined feature is the crater **Letronne**.
**Rille**

- **Rille** is typically used to describe any of the long, narrow depressions in the lunar surface that resemble channels.

- Typically a rille can be up to several kilometers wide and hundreds of kilometers in length.

**Formation**

- Precise formation mechanisms of rilles have yet to be determined. It is likely that different types formed by different processes.
- Leading theories include lava channels, collapsed lava tubes, near-surface dike intrusion, subsidence of lava-covered basin and crater floors, and tectonic extension.

**Types of rille:**

- **Sinuous rilles**
- **Arcuate** rilles
- **Straight rilles**

1. TMC image showing a long sinuous rille situated near the Kepler crater in Oceanus Procellarum.
2. TMC image showing a network of sinuous rilles situated in Oceanus Procellarum.
3. TMC image of Rima Gailei, a sinuous rille in Marius Hill region of Oceanus Procellarum.
The Marius Hills volcanic complex (MHC) is one of the largest volcanic complexes on the Moon consists of a large number of geologic features like cones, domes, rilles, lava flows. The MHC is a 35,000 km² plateau located in central Oceanus Procellarum at 13.3N/306.8E and rising 100–200 m from the surrounding plains. Marius Hills domes are a unique class with irregular shapes, complex surface details, and a few summit craters or cones on top of some domes. Examples of some domes of different shapes and cones with their 3D view from TMC data is shown below.
Study Area:
Marius hills region of Oceanus Procellurum and Tycho crater
Inventory of Lunar domes mapped in Marius Hills region using Chandrayaan-1 Terrain Mapping Camera

Ortho image coverage of Chandrayaan-1 TMC

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<th>Lat</th>
<th>Long</th>
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<th>Diameter</th>
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Searching DEM data for a location: -58.612 E (301.388E) and 11.78 N
DEM Product ID: TMC_NRD_20090113T183335_1_AN
ORBIT NO: 795
Defining projection
Computing Statistics
Null value of DEM=-20000
Crater counting and age determination

- Crater counting refers to a method for estimating the age of a planet's surface.

- Measures the crater densities (craters per square kilometer)
  - Generally a less cratered area is younger than a more cratered area

- The method is based upon the hypothesis that a new surface forms with zero impact craters, and that impact craters accumulate at some known, roughly constant, rate.

- The method has been calibrated using the ages of samples returned from the Moon.

- Impact history of the Moon to be gradually worked out by means of the geologic principle of superposition.
  - That is, if a crater (or its ejecta) overlaid another, it must be the younger.
• Older surfaces have more craters

• Small craters are more frequent than large craters

• Relate crater counts to a surface age, if:
  – Impact rate is constant
  – Landscape is far from equilibrium
    \(i.e.\) new craters don’t erase old craters
  – No other resurfacing processes
  – Target area all has one age
  – You have enough craters
    • Need fairly old or large areas

• Techniques developed for lunar maria
  – Telescopic work established relative ages
  – Apollo sample provided absolute calibration
An ideal case...

- Crater population is counted
  - Need some sensible criteria
e.g. geologic unit, lava flow etc...
  - Tabulate craters in diameter bins
  - Bin size limits are some ratio e.g. $2^{\frac{1}{2}}$

- Size-frequency plot generated
  - In log-log space
  - Frequency is normalized to some area
- Piecewise linear relationship:

- Vertical position related to age
- These lines are isochrones
Methodology:
1. Selection of region (geologically homogeneous unit)
2. Mapping of primary crater diameters and measurement of diameters
3. Measurement of the surface area
4. Age determination using Craterstats tool

Assumptions
1. Crater formation is geographically random process
2. Processes destroying the craters operate much more slowly than crater formation processes

Softwares:

ERDAS: Mapping craters and measurement of diameters.

Crater tools in ARCGIS: Mapping of craters, Area of interest and measurement of diameters

Craterstats: Plotting cumulative crater frequency, production curve fitting and surface age determination

Chronology function curve changing rate (constant back to 3 Ga, then exponentially increasing)

Production function curve constant size-frequency distribution
Craterstats software – surface age determination

- Production function
- Chronology function
- Diameter range
Craterstats software – sample measurement

• Start
  – Download from:
    • http://hrscview.fu-berlin.de/software.html
  – On Windows, double-click craterstats.sav; on linux: type idl -vm=craterstats.sav

• Make cumulative histogram plot
  – Use pre-binned count (Echus Chasma, Mary Chapman):
    • sample/ECHUS_CHAP_AR1_A.stat
  – Select the source file for the count using the ‘Browse…’ button
  – Set the axis ranges

• Make first fit
  – Duplicate first plot (File-duplicate), and change plot-type to ‘fit’
  – Choose production function
  – Select fit range
  – Options: age, error bars, isochron

• Make 2nd fit (younger part)
  – Duplicate previous plot
  – Modify fit range
  – Hide plot

• Make resurfacing correction
  – Duplicate first plot
  – Change colour/symbol
  – Modify diameter range
  – Enter minimum fitting diameter for correction
  – Check ‘resurfacing correction’ box

• Make fit to corrected points
  – Duplicate previous plot
  – Change plot type to ‘fit’
  – Set minimum diameter equal to the ‘minimum fitting diameter’
  – Display age/isochron
  – Option: align left

• Export graphic
  – Export image as .png file, or as postscript
  – Save composite plot (File-Save…)
  – Examine .plt and .txt output files (both ASCII)
Craterstats software - overview

- Import, bin and plot crater counts
- Fit a production function
- Obtain an age from a chronology function
- Plot isochrons
- Apply resurfacing correction
- Export graphic

http://hrscview.fu-berlin.de/software.html

- Detailed instructions:
  http://hrscview.fu-berlin.de/craterstats.html
Craterstats software – data

- area
- diameters
- binning (Neukum’s pseudo-log bins, Hartmann’s root-2 bins, unbinned)
- error bars

#Model .diam file for Craterstats

#Area <km^2> = 123.45

#diameter, km

0.25
0.38
0.22
0.22
0.33
0.6
0.32
0.36
0.16
0.26
0.22
0.16 ......
• Distribution falls below PF
• Simple fit in error because of excess in larger diameter range
• Slope appears shallower
• Find excess by fitting slope
- Distribution falls below PF
- Simple fit in error because of excess in larger diameter range
- Slope appears shallower
- Find excess by fitting slope

**Craterstats software – resurfacing events**

![Graph showing cumulative crater frequency vs. crater diameter with annotations for raw count and with resurfacing correction, indicating a age of 3.69 ±0.07 Ga.]
Craterstats software – resurfacing events

- Distribution falls below PF
- Simple fit in error because of excess in larger diameter range
- Slope appears shallower
- Find excess by fitting slope
- Obtain age from chronology function in the usual way
Surface age determination: A case study from Marius hills region

Cumulative Crater Size Frequency Distribution (CSFD) plots for regions: (a) Mare-2 region excluding dome, (b) dome under study and c) Mare-1. Locations of these regions outlined by Red, Blue and Green colors respectively in (a). PF: Production Function, CF: Chronology Function
DEM Product ID: TMC_NRD_20090113T183335_1_AN
ORBIT NO: 795

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**Lunar Global data sets:**

**Website for browsing Chandrayaan-1 TMC and HysI data sets:** [http://issdc.gov.in/CHBrowse/index.jsp](http://issdc.gov.in/CHBrowse/index.jsp)

**PDS Geosciences Node Lunar Orbital Data Explorer (ODE):** [http://ode.rsl.wustl.edu/moon/index.aspx](http://ode.rsl.wustl.edu/moon/index.aspx)

The **PDS Geosciences Node Lunar Orbital Data Explorer (ODE)** provides search, display, and download tools for the PDS science data archives of the Lunar Reconnaissance Orbiter, the Clementine, the Lunar Prospector, and the Indian Space Research Organisation's Chandrayaan-1 missions to Earth's moon.

**Planetary names of features on Moon:**
- [https://planetarynames.wr.usgs.gov/Page/MOON/target](https://planetarynames.wr.usgs.gov/Page/MOON/target)

**Lunar Reconnaissance Orbiter’s Wide Angle Camera (WAC) global morphological map/mosaics**
- [http://wms.lroc.asu.edu/lroc/view_rdr/WAC_GLOBAL](http://wms.lroc.asu.edu/lroc/view_rdr/WAC_GLOBAL)

**LRO WAC global mosaic of 500 m spatial resolution:**
- [http://lroc.sese.asu.edu/data/LRO-L-LROC-5-RDR-V1.0/LROLRC_2001/DATA/BDR/WAC_GLOBAL/WAC_GLOBAL_E000N0000_064P.IMG](http://lroc.sese.asu.edu/data/LRO-L-LROC-5-RDR-V1.0/LROLRC_2001/DATA/BDR/WAC_GLOBAL/WAC_GLOBAL_E000N0000_064P.IMG)

**LRO WAC global DTM mosaics:** [http://wms.lroc.asu.edu/lroc/view_rdr/WAC_GL100](http://wms.lroc.asu.edu/lroc/view_rdr/WAC_GL100)

**LRO LOLA global topography data:**
- [http://geo.pds.nasa.gov/missions/Iro/lola.htm](http://geo.pds.nasa.gov/missions/Iro/lola.htm)
- [http://pds-geosciences.wustl.edu/Iro/Iro-l-lola-3-rdr-v1/Irolol_1xxx/data/lola_gdr/](http://pds-geosciences.wustl.edu/Iro/Iro-l-lola-3-rdr-v1/Irolol_1xxx/data/lola_gdr/)
- [http://pds-geosciences.wustl.edu/Iro/Iro-l-lola-3-rdr-v1/Irolol_1xxx/data/lola_gdr/cylindrical/jp2/ldem_64.jp2](http://pds-geosciences.wustl.edu/Iro/Iro-l-lola-3-rdr-v1/Irolol_1xxx/data/lola_gdr/cylindrical/jp2/ldem_64.jp2)
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**Craterstats and cratertools softwares:**
Thank You