Retention time of Crater Ray Materials on the Moon

本田邦寿
公立大学法人会津大学
先端情報科学研究センター
Crater Ray

- Fresh materials not be affected by space weathering
  → Bright compared with the surrounding materials

- Formed by excavation and deposition of fresh materials from both the primary crater and the secondary craters (Hawke et al., 1999, 2000)
• Surface materials are modified by exposure to cosmic rays, solar wind, and meteorite bombardments (Sasaki et al., 2001)
Space Weathering (2)

- Effects of space weathering
  - Darkening: Surface reflectance becomes low
  - Reddening: Visible range is darker than near infrared
  - Weakening of absorption band depths

Sasaki et al. (2001)
Crater Ray

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Cumulative Crater Frequency, 1/km²

- Copernicus crater’s floor
- Copernicus crater’s ejecta blanket

- 4% saturation equilibrium
- 3.8 Ga
- 3.2 Ga
- 1.0 Ga

Crater Chronology (NPRF)
Reasons for Disappearance of Rays

• Rays disappear in 1.1 Gyr (Wilhelms, 1987) 、750 Myr (0.75 Gyr) (Werner and Medvedev, 2010)

• **Space weathering** acts directly on surface materials

• **Gardening**
  – Surface materials are mixed with surrounding space weathered materials by micrometeorite bombardments
現在
時間の経過
1.1 Gyr (Wilhelms, 1987)
0.75 Gyr (Werner and Medvedev, 2010)

A crater
B crater
C crater
D crater
E crater

光条(ray)見えない
風化しきっている

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時間の経過  現在
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月の地質区分
Eratosthenian - Copernican

光条をもつクレーター: Copernican
光条をもたないクレーター: Eratosthenian

USGS作成の詳細地質マップ

Wilhelms (1987)
Objective

Investigate retention time of crater rays using high-resolution data from Terrain Camera and Multiband Imager onboard Kaguya
## Analysis Areas

<table>
<thead>
<tr>
<th></th>
<th>Longitude</th>
<th>Latitude</th>
<th>Areas [km²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0° N – 15° N</td>
<td>147.5° E – 148.1° E</td>
<td>8.3 × 10³</td>
</tr>
<tr>
<td>2</td>
<td>0° N – 15° N</td>
<td>148.5° E – 149.2° E</td>
<td>8.3 × 10³</td>
</tr>
<tr>
<td>3</td>
<td>15° S – 0° N</td>
<td>143.2° E – 143.5° E</td>
<td>8.1 × 10³</td>
</tr>
<tr>
<td>4</td>
<td>15° S – 0° N</td>
<td>144.3° E – 145.1° E</td>
<td>8.1 × 10³</td>
</tr>
</tbody>
</table>

**MI 750 nm image**

**OMAT**

Legend:

- 0.1
- 0.5
Crater with Bright Ray
Crater with No Ray
Optical Maturity Parameter (OMAT) (Lucey et al., 2000)

- Optical index representing the degree of space weathering (Low OMAT value means mature soil)
- Definition:

\[
OMAT = \sqrt{(R_{750} - x_0)^2 + \left( \frac{R_{950}}{R_{750}} - y_0 \right)^2}
\]

- \(R_{750}\): Reflectance at 750 nm
- \(R_{950}\): Reflectance at 950 nm
- \(x_0 = 0.08, \quad y_0 = 1.19\)
- Calculate from multiband data obtained by MI
Space Weathering (2)

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[Sasaki et al. (2001)]
Space Weathering (2) つづき

反射率が全体的に低くなる

吸収深さが浅くなる

Lucey et al. (2000)

Sasaki et al. (2001)
手順

• TCデータ（低太陽高度条件データ）を用いて、計測領域内の直径300m以上の地形の形状から判断して新鮮なクレーターをリストアップ

• MIデータを用いて、リストアップしたクレーターのOMATプロファイルを調べ、光条の有無を判定する
OMAT and Crater Rays

- OMAT value of ray materials is high
- OMAT value of rayed craters
  - High at the crater rim
  - Decreases with the distance from crater rim

**OMAT Profiles**
- Calculate radial average OMAT value
- Normalized distance from crater center by crater diameter
Rayed Craters Extraction

1. Identify craters larger than 300 m in diameter in TC image
2. Extract rayed craters based on the following criteria:
   - OMAT value at the crater rim is larger than 0.15
   - OMAT value decreases with the distance from crater rim
Background OMAT Value

0.14 ± 0.01
Rayed Craters Extraction

1. Identify craters larger than 300 m in diameter in TC image
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   - OMAT value at the crater rim is larger than 0.15
   - OMAT value decreases with the distance from crater rim

![Graph showing OMAT value vs. distance from crater center]
## Number of All Craters and Rayed Craters

<table>
<thead>
<tr>
<th>area</th>
<th>Num. of all craters</th>
<th>Num. of rayed craters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>D &gt; 1 km</td>
</tr>
<tr>
<td>1</td>
<td>124</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>133</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>109</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>151</td>
<td>26</td>
</tr>
<tr>
<td>Total</td>
<td>517</td>
<td>68</td>
</tr>
</tbody>
</table>
Crater Size-Frequency Distribution

- Deviated from 750 Ma isochron (Wener and Medvedev, 2010)

\[ D > 1.3 \text{ km} \]
- Distributed between 2 Ga and 3 Ga isochrons

\[ D < 800 \text{ m} \]
- Fall below 750 Ma

Inconsistent with previous researches
Rayed Craters Extraction

Average OMAT value vs Distance from Crater Center in Diameter
Pattern of Ray Disappearance

Plots of normalized OMAT value
- The craters larger than 800 m in diameter and that smaller than 800 m are plotted.

Num.D<800m : Num.D>800m
≈ 4 : 1
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Precise Inspection of Rayed Craters

- Confirm existence of rays using image data
- Focus on craters larger than 1 km in diameter
- Investigate based on MI 750 nm image, OMAT, and OMAT profile
Precise Inspection of Rayed Craters

- OMAT values at the rim affect due to tiny fresh craters around a crater
- OMAT values also affect due to overlapped ejecta from a neighborhood rayed crater

Eliminate such craters
Comparison with Werner and Medvedev (2010)

- Our result obviously shows that there are more rayed craters in these areas than Werner and Medvedev (2010).
- We also strongly suggest that retention time of rays is substantially longer than 750 Myr.
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時間の経過

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Clementine: 8 bit（過去研究）
Kaguya, MI: vis 10 bit, nir 12 bit

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Lunar Iron Map

Lucey et al. (2000)
光学的成熟度

- OMATは反射率スペクトルの1000 nm付近の吸収の深さに着目したパラメータ
- そもそも月高地には、1000 nmに吸収を持つ鉱物（olivine、pyroxene）がほとんど含まれないため、OMATは不適当かもしれない
- OMAT以外に、スペクトルの傾きを利用した光学的成熟度を示すパラメータを作ってみるとよいかも
Space Weathering (2)

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[Sasaki et al. (2001)]

[Image 1]: A graph showing the effects of space weathering on reflectance at different wavelengths, with annotations and a comparison to Lucey et al. (2000).
Conclusion

• OMAT is useful for ray detection
  – Need to investigate based on not only OMAT profile, but also OMAT map

• Retention time of rays
  – Longer than the previous results
  – Highly depending on crater size
    → Valuable information to understand mechanism of rays disappearance
Thank you for your kind attention.