Briefing Topic:

Crater Slopes & Roughness

David A. Kring
Crater Slopes and Roughness

• Central Lunar Highlands
  – Apollo 16
  – Impact cratered terrain
  – Descartes Formation highlands (Nectaris Basin ejecta, VHA melts, and anorthositic debris)
  – Cayley Formation plains (a Bunte Breccia-like deposit created when Imbrium Basin ejecta landed and reworked the upper portion of underlying Nectaris debris; primary Imbrium ejecta in the formation is less abundant than reworked Nectaris ejecta)

• Lunokhod Lessons

• LExSWG (1995) Conclusions
Apollo 16 Landing Site

Surface: John Young and Charlie Duke
Orbiting: Ken (or TK) Mattingly
Apollo 16 Landing Site

Surface: John Young and Charlie Duke
Orbiting: Ken (or TK) Mattingly
Apollo 16 Landing Site

- Landed on western interior wall of subdued 180 m diameter crater and 10 m west of moderately subdued 30 m diameter crater

- 1.3 to 6% of surface is covered by rocks ranging from 2 to 20 cm in size; average surface coverage is 2%

- Blocks as large as 0.5 m are relatively common

- The largest boulder is several meters across

- Rocks are not deeply buried
Focus on North Ray Crater

Surface: John Young and Charlie Duke
Orbiting: Ken (or TK) Mattingly
North Ray Crater Ejecta
North Ray Crater
North Ray Crater

Station 11

B₁  67075  B₄  67435
   67415        67475
   67955        67915

B₂  67015  C₂  67935
   67016        67936
   67035        67937
   67055
   67115  G  67095
   67455
   67975

Station 13

B₄  60017  63355
North Ray Crater (Apollo 16)

- 1 km diameter, 230 m deep
- 50 million years old (Copernican; Arvidson et al., 1975; Maurer et al., 1978)
- Excavated from a target of older impact ejecta (Nectaris Basin debris, plus Imbrium Basin debris that reworked uppermost portion of Nectaris debris)
North Ray Crater (Apollo 16)

- 1 km diameter, 230 m deep
- 50 million years old (Copernican; Arvidson et al., 1975; Maurer et al., 1978)
- Excavated from a target composed of older impact ejecta (Imbrium and reworked by Nectaris)
North Ray Crater Geology

(a)

(b)

Active debris slides
Crater
Possible stratification
Original ground surface
Far horizon
Crater rim
Slump block
Stable talus slope
Bench
Near horizon
Fig. 6-60(c)

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Lunar Exploration Initiative
2006
North Ray Crater Interior Slopes

- Possible bedrock exposure in upper center of crater wall
- Original surface visible beneath ejecta on crater rim
- Debris slides dominate interior crater walls

Interior crater wall slope, North Ray Crater, looking north (AS16-106-17241)

Michelle et al. (Apollo 16 Preliminary Science Report)
North Ray Crater Interior Slopes

- Angular and subangular cobbles to large boulders, separated by smooth slopes of lunar soil, cover most of interior crater wall surfaces.

- Blocks in this image of the NE crater wall measure ~10 m; they are composed of light-matrix breccias.

- Largest rock ("House Rock") exposed at the crater is 25 m long and 12 m high; it sits on the SE crater rim.
North Ray Crater Interior Geology

- Original crater walls exposed on east side; outcrops of 10 m size rock are indicated by black spots

- Old debris flows are visible on SW, W, and N walls (hatchered areas)

- Newer debris flows are visible around entire crater (white lobes with arrows indicating flow directions)

- Crater center rises slightly and is blocky

- Rim crest is eroded
North Ray Crater

A16, North Ray Impact Crater
(note excavated rock, but otherwise smooth surface)

- Rocks >10 cm in size cover only 4.3% of surface on crater rim

- Value falls to 0.5% on outer ejecta blanket, with only ~1/4 the number of fragments

- 0 to 2% of the rocks between these two areas are >2 cm in size

- 20% of rocks are larger than 20 cm on crater rim

- Value falls to 10% on outer ejecta blanket

Muelberger et al. (1972); Ulrich (1981)
# North Ray Crater Block Sizes

**Size distribution and shapes of blocks at North Ray Crater**

**Crater rim crest (Station 11)**

<table>
<thead>
<tr>
<th>Size</th>
<th>10-20 cm</th>
<th>20-50 cm</th>
<th>&gt;50 cm</th>
<th>Shape %</th>
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<tr>
<td>Rounded</td>
<td>145</td>
<td>35</td>
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<td>69.0</td>
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<td>Subangular</td>
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**Outer ejecta blanket (Station 13)**

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Ulrich (1981)
North Ray Crater

- 55° slopes were estimated in rocky areas and 40 to 45° slopes were estimated where covered with soil (Michell et al., Apollo 16 Preliminary Science Report)

- Final report (Ulrich, 1981), however, concluded a convex upper slope ranges from 27° at top to 34° in lower half of crater wall. (Only the upper 60% of crater wall is visible from Station 11.)

- Rounded crater rim, relatively smooth walls with few blocky areas, and breccias among ejected samples indicate the target rock is composed of weak breccias
North Ray Crater

- Topography
- 5 m contours
- 230 m deep
- Shadowed region from orbit (area with only 25 m contour interval)
- Hidden region from Station 11 (area that is hatched)

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Ulrich (1973, 1981), after Nakata
A light-matrix impact breccia appears to overlie a darker-matrix breccia in the target.

An impact-generated central uplift, suggested in this cross-section, is unlikely based on our current understanding of simple craters; a pre-existing anticline is possible, however.
Comparison: 1 km Craters

North Ray Crater (~1 km)  Barringer/Meteor Crater (~1.25 km)
Comparison: 1 km Craters

- North Ray Crater is ~1 km in diameter, 50 Ma, on an airless body with 1/6 Earth’s gravity, where the dominant erosional process are other impact events.

- Meteor Crater is ~1.25 km is diameter, 50 ka, on a body with a climatically-active atmosphere, although a region where it has been arid for the past 10 ka.

Ulrich & Reed (1981), after Nakata (NRC) and Shoemaker (MC)
Comparison: 1 km Craters

- Original topography of North Ray Crater (NRC) may have been more subdued than that at Meteor Crater (MC), because it was composed of weaker lithologies (impact breccias rather than sandstone, dolomite, and siltstone)

- Debris slides at NRC eroded rim, buried crater walls, and buried part of crater floor

- Crater wall slopes at NRC are less than those at MC

- Area of relatively flat crater floor is smaller at NRC than at MC
Focus on South Ray Crater

Surface: John Young and Charlie Duke
Orbiting: Ken (or TK) Mattingly
Astronauts did not reach South Ray Crater, so they were unable to provide details about block sizes on continuous ejecta blanket, crater rim, and interior crater walls.
South Ray Crater (Apollo 16)

- Oblique “aerial” view from Orion (LM)
- Uplifted rim with ejecta blanket
- 680 m diameter crater
- 2 million years old (Arvidson et al., 1975); thus, this is a much fresher crater than North Ray Crater
South Ray Crater (Apollo 16)

- Ejecta blanket and rim have slopes of 7° or less
- Interior crater walls have slopes as high as 35°
- Routes to crater floor exist, however, with slopes of 17 to 26°
Lunokhod Lessons

Lunokhod 1 (Luna 17)
Lunokhod 2 (Luna 21)
Lunokhod Lessons

• Soft soils
  – Lunokhod 2 encountered soft soils on the inside walls of craters; the soil was particularly soft at the base of slopes
    • Normal wheel sinkage was 2 cm
    • Wheel sinkage was >20 cm near impact craters

• Cohesion varies as a function of geologic terrain
  – Cohesion on interior crater rims is less than that in intercrater areas
  – Cohesion in intercrater areas is less than that on crater rims
LExSWG Conclusions

• LExSWG (1995) findings for rover mobility
  – Impact-cratered terrains
    • Old 100 m diameter crater (a common feature) has maximum slopes of 5 to 10°
    • Somewhat fresher craters have interior slopes of 15 to 20°
    • A very fresh crater, 500 m diameter South Ray Crater, has ejecta blanket and rim slopes of 7° or less; interior crater wall slopes can be as high as 35°, but routes to crater floors with slopes of 17 to 26° exist
    • Even large craters with diameters >10 km have average crater wall slopes <30°
    • Conclusion: capability to ascend and descend slopes of ~25° is sufficient
LExSWG Conclusions

- LExSWG (1995) findings
  - Volcanic terrains
    - Near vertical walls will occur near rilles, but less steep routes to rille floors exist
    - Topographic study of Rima Prinz and Rima Mozart reveal numerous routes to rille floors with slopes of 15 to 20°; routes with slopes <15° also exist
    - Conclusion: capability to ascend and descend slopes of ~25° is sufficient