The Nature and Origin of Boulder Piles in Eastern Mare Serenitatis

by Moon Crew,
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• We learned to use LROC!
• Got sidetracked into too many projects, all of which were cool!
• We compared Mare Serenitatis (MS) with neighboring Taurus-Littrow (TL) highlands: kinds and numbers of craters and boulders, rolling boulders, nature of the surfaces in MS and TL; search for volcanic features; physics on the moon.
• **Today's Report: Scaling LROC and Boulder Piles**
Seacrest Moon Crew Project

• Part 1: Measuring the size of objects using LROC
• Part 2: Finding boulders and boulder piles
• Part 3: Falling Ejecta Boulders
• Part 4: The Velocity and Energy of Collisions on the Moon’s Surface
• Part 5: Why the Boulder Piles look the way they do: Blanket of Fine Ejecta
David: How Big is this?
Sizing LROC Images

✧ 1. Problem: how big is everyone’s image?
✧ 2. Each pixel in LROC NAC is .5 Meters
✧ 3. Zoomify can’t Zoom in on LROC to a pixilated level
✧ 4. We are also using screen captures that do not preserve original pixilation.
✧ 5. I used Preview/Irfanview/ImageJ to count pixels and Measure size
We know exactly how big something is! The LEM is 4.3 meters across.

We studied 40 pairs of LROC NACs, 20 in MS, 20 in the highlands to east of MS (Taurus-Littrow area)
Confirming Size

- First, I had to download the image file (.tiff) from LROC (NAC image #M109032389LC)
- Preview (MAC default image editor/viewer)
  - Opened image in Preview, counted pixels (confirmed .5m by using the Lunar Lander)
Counting pixels in **Preview (Mac)**

- The simplest yet most unproductive way
- Zoom in to full zoom (pixilated) on downloaded image
- Count pixels by finger, use annotation tool for scale
Irfanview sizing tool:

- The second most effective method and pretty simple
- Open up the downloaded image
- Click on “show paint dialog” (in Edit) , then select the measure tool (looks like a protractor)
Sizing using ImageJ (mac and pc compatible)

– Open image in ImageJ (must be converted to .jpg), Set scale under “measure,” draw line, click analyze, will tell you size in meters
These three programs preserve original pixilation in .tiff and .jpg formats, so the .5m/pixel scale works

- But **Screen capture** does not preserve original pixilation

- To solve this we used the known width of the strips, approximately 5000 pixels
Full width NAC strip is 5000 pixels wide = 2500 meters

*Determine the screen scale for any capture screen image (Print Screen, Snip, etc.) by viewing the entire width, measuring that with a ruler, compute scale.
Dan: **Part 2: What “Moon Crew” found.**

- We studied 40 pairs of LROC NACs, 20 in MS, 20 in the highlands to east of MS (“Taurus-Littrow area”)
- We needed to know the size of things because we have found multiple, clear images of boulder piles (BPs) in, around, and away from craters.
- Upon close examination, the isolated piles (not in craters) look as if they were gently dropped there. They do not look as if they hit with a large amount of kinetic energy.
- How did they get there? There seems to be no evidence
Typical lunarscape with no objects
(scale 2 km wide, TL)
Boulder Piles were seen as isolated or groups of large boulders (3-20 meters diam)
Small boulder pile (BP)
Large BP
What are BPs and where are they from?

There appear to be different kinds of BPs.

None came from any kind of volcanic feature.

BPs are very rare in Mare Serenitatis.
3: We observed 2 kinds of BPs

1. BPs that must have fallen from the sky: crater ejecta

2. BPs that are part of local shattered bedrock; **Connected to ground**, (not sitting on top) or boulders along and on crater wall structures, rilles, or ridges

Today we are only reporting on 1, Falling rocks……
Falling rocks

• If ejecta fell from “space”, it
  -- should leave some impact marks
  -- should roll, leave bounce marks
  -- should smash and break apart
  -- might leave a color mark on the surface
  -- could have any shape or size

But we observed............
No obvious associated craters
30 meter pile, no sign of impact
Boulder trails: they do make marks
Large rock to right: where is its impact hole(s)? (10m, 1000+tons)
Even definite ejecta does NOT appear to make markings

Light colored surface marking leading to boulders may be from nearby crater
Appears to be a splatter pattern, but no clearly associated craters on the surface.
This impact **did** make slight indent

*(only such feature found)*
Slight evidence of impact marks. Left object appears slightly buried by debris; far right boulder sits in crater.
Dan: **Problem:**
The mystery of the BPs is their origin. Why no obvious bounces or crater markings. Are they concealed:

- by slow speed “arrivals” with low energy?
- with a thick cover layer of light, consolidated ejecta? (“snow”)
- by erosion (radiation, solar wind) which has covered area of BPs?
- by their great age?
- Any combination of above.
Why don’t we see common impact marks around boulders?

- LROC analyst James Ashley says:
  “…this rubble represents a portion of fall-back debris deposited shortly after crater formation, mixed with subsequent landslide debris, and partially covers the floor of a small, fresh crater …... If this loose rubble were to become buried, compacted, and lithified, we would call the resulting rock an impact breccia.”

- That is an example of the kind of cover blanket that we think is created by high energy huge impacts which may bury other smaller boulder impacts.
Apollo landing sites on firm, light dusty surface: Evidence of solid layer of compacted layer composed of ejecta materials
TEST: What the collision is like:

• density of rock =~ 3 metric tons/m$^3$ or 6600kg/m$^3$.
• a 10 meter cube bldr is 3000 tons = 6.6 million kg! ($10.6 \times 10^6$N, $2.6 \times 10^6$ lbs)

• Why don’t they make a hole in the ground when falling?
Answer: they must, we’re just not seeing it.
Ejected boulder landing speeds

- (Takes off and lands at the same velocity, assume 45 degrees launch)
  - 2000m  \( V = 56 \text{ m/s} \) or \( \sim 120 \text{ mi/hr} \)
  - 10,000m  \( V = 126\text{m/s} \) or \( \sim 250 \text{ mi/hr} \)

- Either case, these are NOT huge velocities
Greater ejecta distance

- **100km** trajectory = 400m/s or ~ 800mi/hr
- **1000 km** = about 1300m/sec or 2600mi/hr

- Any object traveling this far, must have these velocities: Now we are speeding!
Max: Kinetic Energy Released

- By a 1 meter boulder traveling a horizontal distance 10,000m
  
  \[ K = \frac{1}{2}mv^2 = \frac{1}{2} \times 3000 \text{ kg} \times (16,000 \text{ m}^2/\text{sec}^2) \]

- \(24 \ 000 \ 000 \ \text{joules} \approx \text{several pounds of dynamite}\)

- A Really Large Boulder 1000m\(^3\)=

  \[ 24 \times 10^9 \text{ J} \text{ or } 1 \ \text{ ton of dynamite} = \text{a lot!!!} \]

- It should make a dent in the surface
Meteor Crater, Ariz.

- Nearly 1 mile across and 550 ft deep
- 28,000 mph object with a mass of 300,000 tons: faster, more mass than our boulder ejecta
- About 20 million tons of TNT, MORE than any of our little lunar craters
- Boulders seen in crater wall and area, but most are pulverized or melted: similar to Moon
- Surrounding area showered with fine debris, chunks, and boulders of all sizes: like Moon
Dan: Conclusions

• Why no or few impact marks?
  * Very low speed impacts do not leave observable trace: NOT LIKELY
    (Higher speed impacts are more likely given distances ejecta travels, would result in mini-craters)
  * Blanket ejecta from large impacts and solidified lunar soil has covered all traces of landing marks. LIKELY (Markings are there, we don’t see them)
  * Blanket ejecta is molten: Possible (>next slide)
(left) No objects visible: is this made by **liquid** ejecta: lava? (not solid rocks)

(right) The rubble in the photo is from an impact debris that **melted** together (LROC Gallery)
Study of BPs may give clues as to age of events or land surfaces

- No “dents” in highland may mean it is covered by very old, thick and fine ejecta layer
  -- may confirm that Mare Imbrium (MI) debris covers highlands, but not Mare Serenitatis which is more recent and obliterated all the MI debris in its area
- (The single “dent” we did see must be more recent)
Other conclusions

• BPs rarely found in Mare Serentatis

• BPs commonly found in highlands east of MS

• Boulder outcrops in crater walls, rilles, rimae very common in MS
BPs falling out of sky
Further work to do

• Closer examination to look for their impact markings
• Looking in other areas (not MS or TL) to see what the ejecta are like.
• Checking Clementine or similar spectroscopic data for these areas to learn about the materials on the surface
Seacrest Moon Crew is

• David Prue, Daniel Ferrao, Max Solow

• Big shout out to A and B period physics classes!

• Thanks to!
  • Advisor: Kerri Donaldson Hanna, Brown University
  • Andy Shaner, LPI
FIN (THE END)