Roughness of Impact Crater Ejecta Deposits on Mercury as a Proxy for Crater Degradation

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SUMMARY

Impact crater degradation has been used to approximate relative ages of craters and geological units on planetary bodies since the Apollo era. Previous metrics for impact crater degradation classification have included qualitative assessments of crater rim modification, observed crater depth, the presence of secondaries, and the condition of the continuous ejecta deposit. However, the approach to characterizing impact crater degradation has been limited by our understanding of external parameters that influence impact crater formation and morphologic change (e.g., variations in target properties, proximity weathering, etc.). In this study, **we investigate whether there is a measureable difference in surface roughness of the continuous ejecta deposits of different degradation states on Mercury**.

1. BACKGROUND

1a. CRATER DEGRADATION

We classified all craters on Mercury ≥40 km in diameter using an updated scheme from Kinczyk et al. (2016). This system breaks down degradation classification based on initial crater size and morphology. This was a key component to the analysis as initial crater morphology was not incorporated in previous classification systems, even though it has been recognized that crater size affects the morphology of the initial crater form.

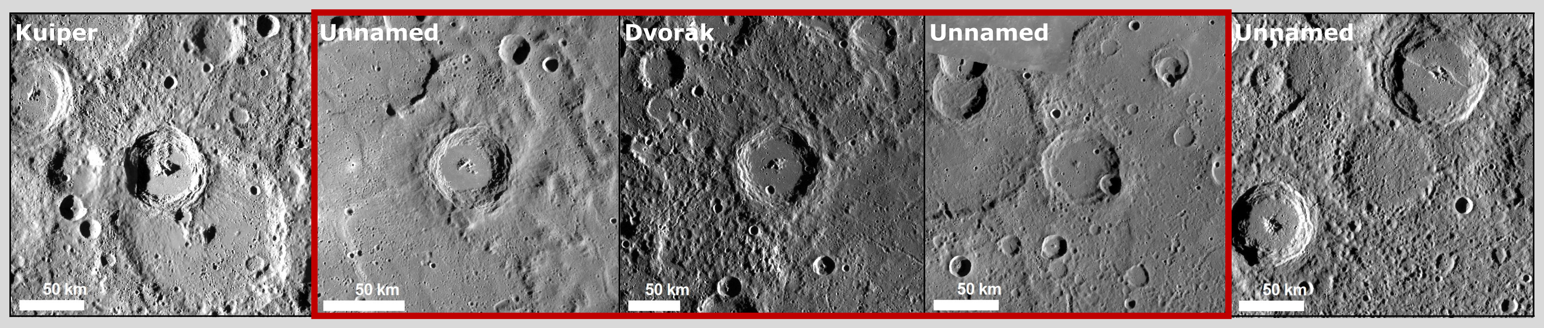


Figure 1. Example from Kinczyk et al. (2016) degradation classification scheme. Fresh craters (C1) have crisp, high rims, continuous ejecta deposits, and bright rays. Very degraded craters (C5) have barely discernible topographic relief relative to the surrounding terrain and their rims are almost completely obliterated. Red outline indicates classes selected for study.

SCIENCE QUESTIONS

1) Is there a measurable roughness difference between the continuous ejecta of Class 2 and Class 3 craters? NO

2) Is there a measurable roughness difference between the surrounding smooth plains regions and the continuous ejecta of craters considered for analysis (using presently available altimetric data)? YES

3) Can we use roughness of continuous ejecta as a metric to determine degradation class? MAYBE

RATIONALE

The ejecta deposits of Class 2 (C2) and Class 3 (C3) craters tend to be relatively well preserved so we focus on these classes in our study. We also selected several Class 4 (C4) craters for comparison. By comparing roughness measurements across craters assigned to these three classes, we seek to identify differences that may represent further evidence of a morphological change over time and to test the basis by which these craters have been classified.

1b. STUDY AREA: Smooth Plains

We selected craters situated within the northern smooth plains and the Caloris interior smooth plains. We assume that the target material in which all of these craters formed is mechanically the same and that none of our studied craters has been noticeably modified by proximity weathering.

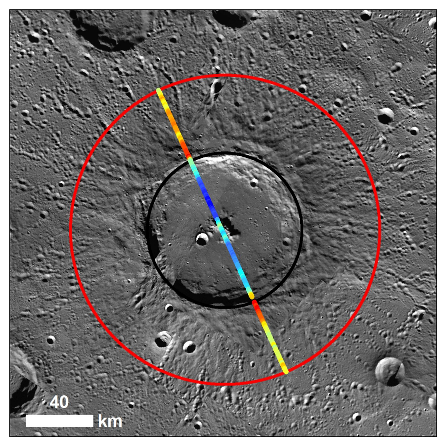
1c. DATA SUMMARY

23 craters total:
- Ten Class 2 craters
- Nine Class 3 craters
- Three Class 4 craters

Mercury Laser Altimeter (MLA) tracks:
- Average of eight profiles per crater
- ~400m uniform data point spacing
- Compared with sampled sections of smooth plains (see Figure 3)
- 181 MLA tracks total

Methods Used:
- Fourier Transform analysis
- Kolmogorov—Smirnov Goodness-of-Fit
- RMS deviation

2. METHODS

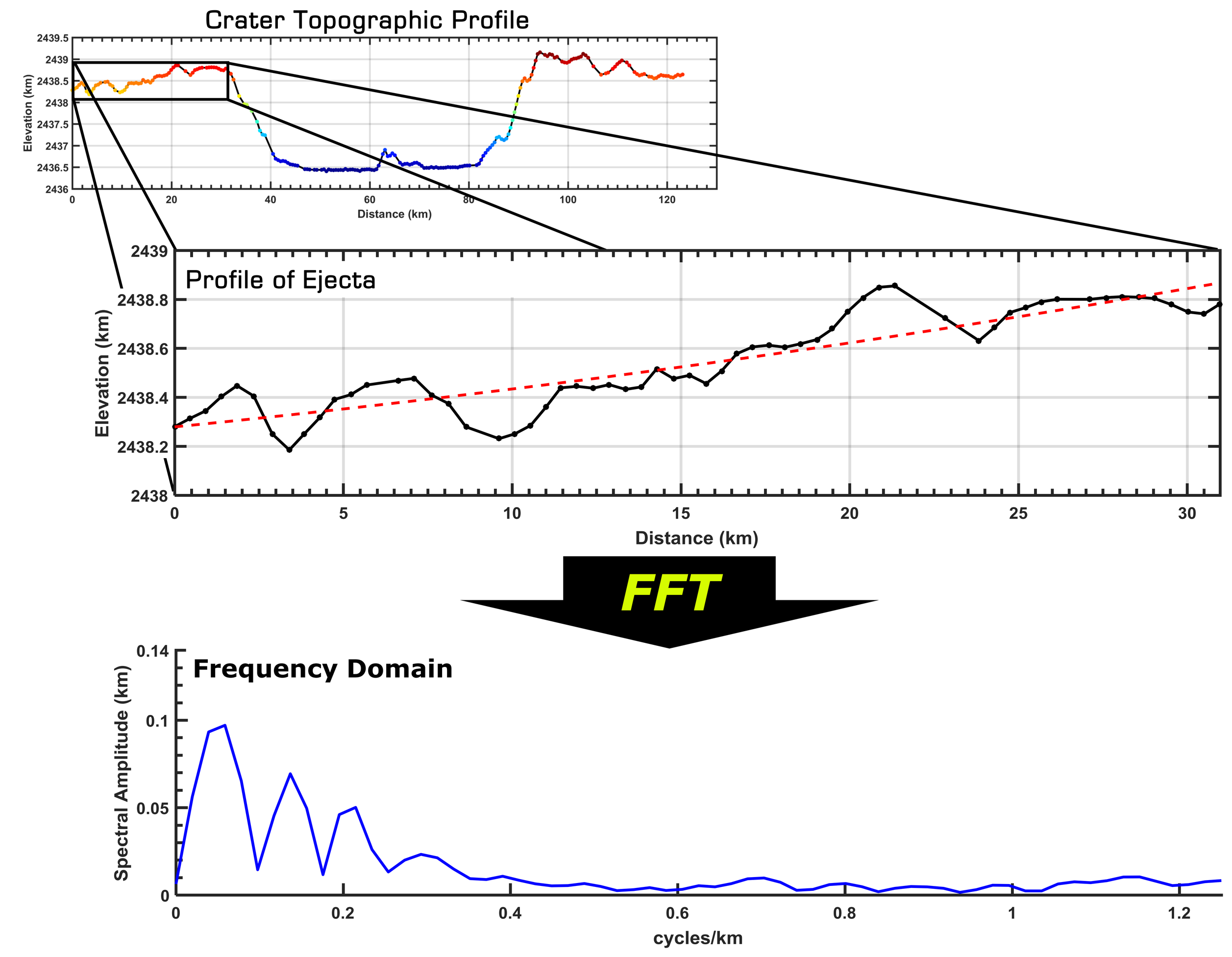


MLA tracks were selected that passed near the center of each crater. The analysis was conducted on the ejecta deposit from the crater rim (black) extending to one crater radius from the crater rim (red). Crater size and form (Mature-Complex to Ringed Peak-cluster basin) were similar for all craters to ensure measurements were commensurable.

Figure 2. Example of crater selected for study with extent of continuous ejecta outlined in red.

2a. FOURIER TRANSFORM ANALYSIS

Fourier Transform analysis is used to convert a signal between the time (or space) domain and the frequency domain. To convert to the frequency domain, the analysis breaks up the series into its constituent frequencies and the output shows how much of each frequency is present in the original data. Here we use the Fast Fourier Transform (FFT) function in MATLAB.



Using a topographic profile, we can apply this method to interpret the roughness of landforms on the basis of the frequencies present in the profile. Here we use MLA tracks to analyze the roughness of the continuous ejecta deposits of C2 and C3 craters.

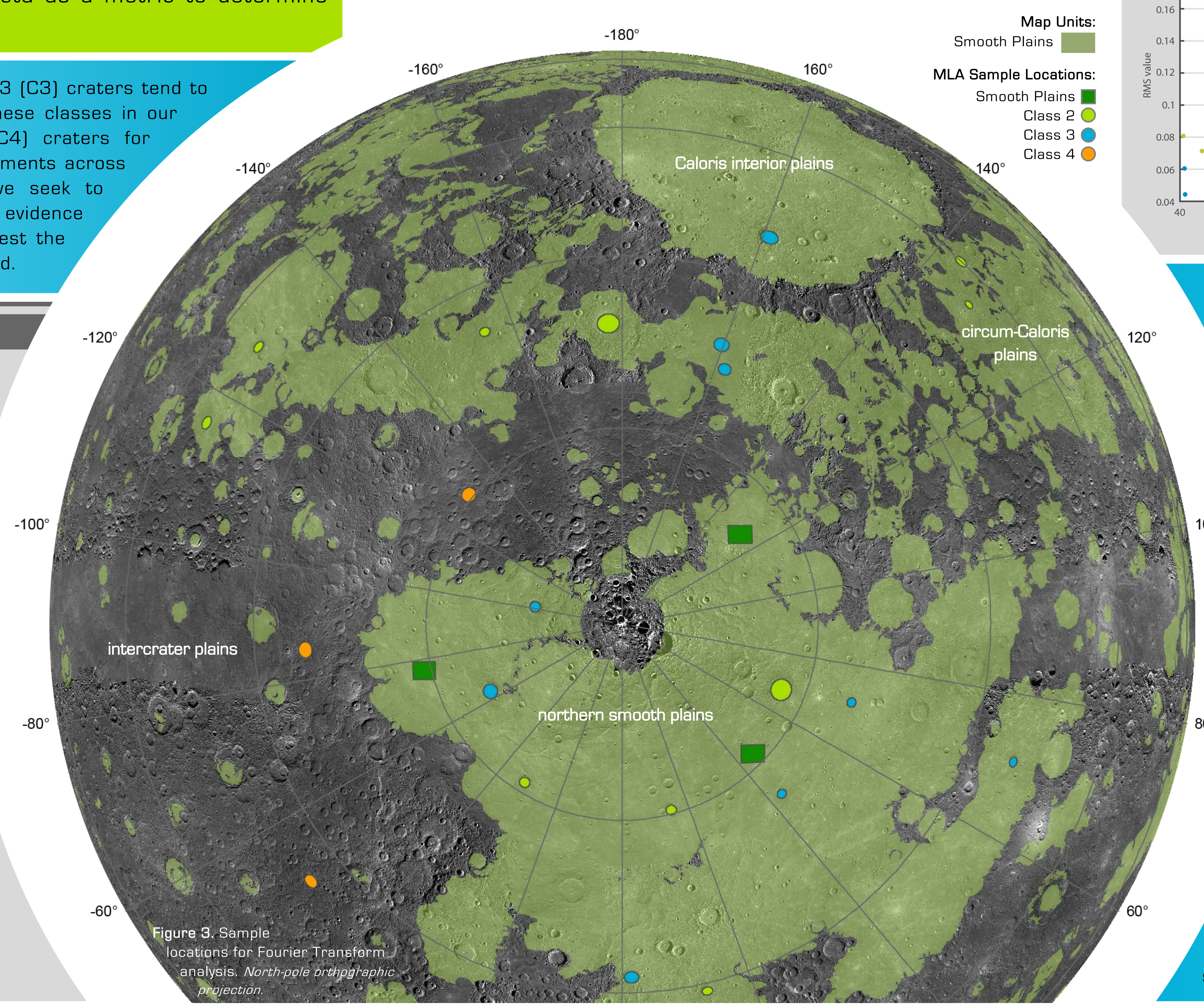


Figure 3. Sample locations for Fourier Transform analysis. *North-pole orthographic projection.*

3. RESULTS

Figure 4. Average topographic frequency for craters compared to smooth plains

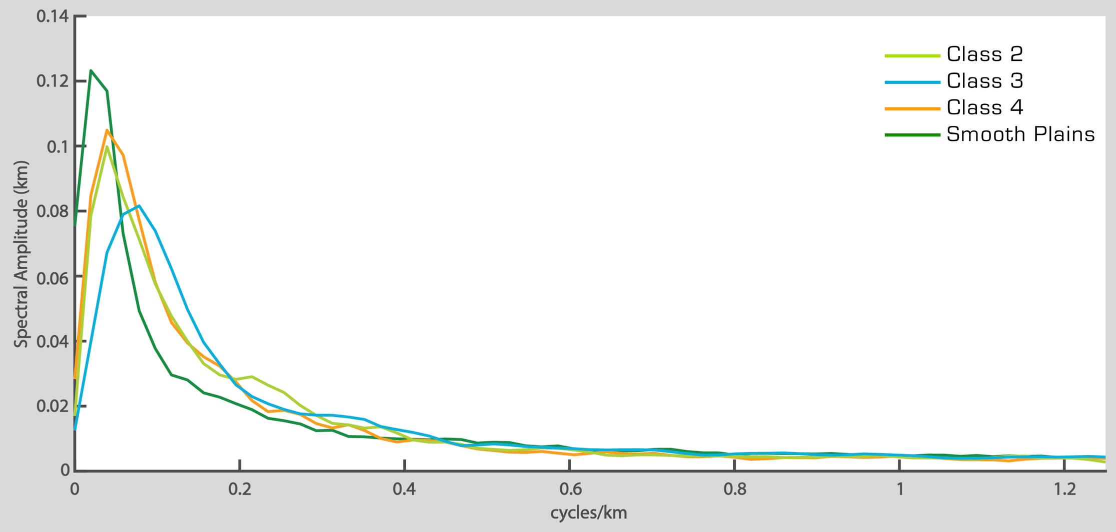


Figure 4 shows the output of the FFT analysis as a weighted average for each crater class to **compare the shapes of the spectral signatures of each unit.** We expected that C2 craters would be dominated by shorter—wavelength topographic undulations, but our results show otherwise. Additionally, it appears that the spectral curve for C2 craters is shifted more towards longer wavelengths than C3 craters.

Kolmogorov—Smirnov Goodness-of-Fit

To measure the difference between each of the spectral signatures in Figure 4, we compare each curve with another using the Kolmogorov—Smirnov goodness-of-fit (KS) test:

$$\mathrm{KS} = \max_i |\mathrm{X}_i - Y_i|$$

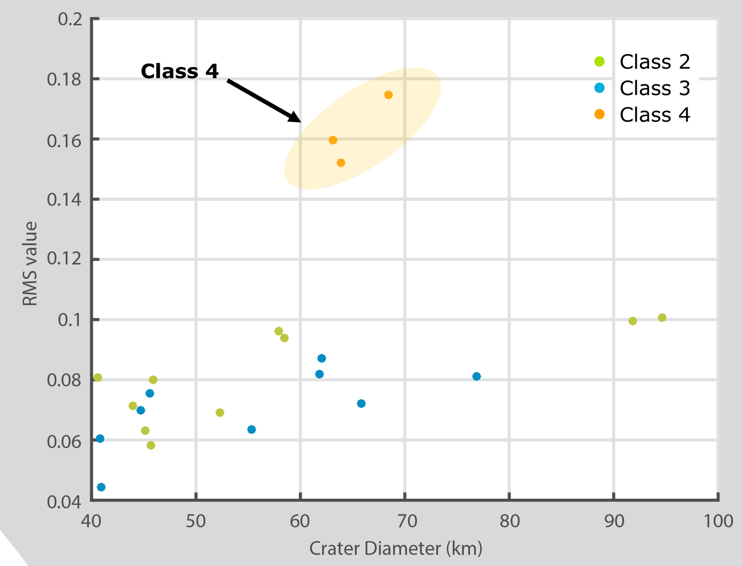
where X_i and Y_i are the spectral curves to be compared.

The results of the KS test are shown in Table 1. These values were compared to a KS critical value of 0.1513 at 90% confidence. As Table 1 indicates, the only statistically significant comparison (one that exceeds the KS critical value) is between Class 3 and smooth plains.

Unit Comparison	KS Value
Class 2 — Class 3	0.0812
Class 2 — Class 4	0.0443
Class 2 — Smooth Plains	0.1202
Class 3 — Class 4	0.1168
Class 3 — Smooth Plains	0.1959
Class 4 — Smooth Plains	0.0975

Table 1. Calculated KS values for compared units.

Figure 5. RMS deviation by crater class & diameter



In order to **compare the overall roughness of each crater class**, we calculated the root mean square (RMS) deviation for the detrended profiles. C2 and C3 show similar RMS values. We also plot RMS deviation for several C4 craters. Figure 5 shows clearly that C4 craters fall within a different roughness regime than the other crater classes. More data will be necessary to confirm this finding.

CONCLUSIONS

1) The continuous ejecta of C3 craters is significantly different from the underlying smooth plains unit, though frequency curves for all units are very similar.

2) Plotted RMS values show that the deposits surrounding C4 craters lie within a different roughness regime than C2 or C3 craters. This was expected as C4 craters were the only samples selected from outside the smooth plains.

3) It is possible that the roughness properties responsible for the qualitative assigning of a given degradation state cannot be resolved with MLA tracks. Any wavelengths shorter than 800 meters are indistinguishable.

At present, visual classification is a more effective method than measuring roughness of ejecta.

FUTURE WORK

- Run comparative analysis on lunar craters using the higher resolution Lunar Orbiter Laser Altimeter data (~20 m resolution).
- Extend analysis to more C4 and C5 craters to compare with present study, and analyze craters within the intercrater plains for comparison.
- Extend analysis to intercrater plains for all classes of craters.
- The BepiColombo laser altimeter (BELA) will have 258 m pulse spacing which will greatly increase the power of this type of test.