

MORPHOLOGICAL CLASSIFICATION OF COMPLEX ERATOSTHENIAN CRATERS C. Rojas¹, P. Mahanti¹, M. S. Robinson¹, ¹LROC Science Operations Center, School of Earth and Space Exploration, Arizona State University, Tempe, Arizona (crojas@ser.asu.edu)

Introduction: Young lunar craters are classified into two age categories based on sharpness of morphology and the presence or absence of high reflectance rays (HRR): Copernican (<1 billion years (By) old) and Eratosthenian (~1 By to ~3.2 By). HRR form as immature material is excavated and deposited at great distances where local immature material is also excavated and deposited on the mature surface [1]. Over time HRR fade due to space weathering processes and eventually are undetectable, except in the case where anorthositic highland material is deposited on mafic mare materials, rays can persist long due to inherent albedo contrast between the two materials [2]. Immature rays can be seen in optical maturity (OMAT) maps up to about 1 By years [3]. Copernican craters can be relative-age classified based on OMAT [4, 5], rock abundance [6, 7], and via radar signals [8, 9]. Since these signatures are muted by 1 By, Eratosthenian craters only offer topographic changes. In this study, topography in non-Copernican young complex craters is explored as a metric of age. We offer a qualitative assessment of crater morphology with quantitative values such as slope and crater volume derived from lunar topography.

Methods: In our analysis, an initial list ($n = 110$) young complex craters previously assessed for terrace width variations [10] was first refined to include craters

Table 1: Complex crater morphology freshness classification

	Class A (rugged)	Class B (smooth)
Rim-crest sharpness	Do not exhibit rounding or minute crenulations	Round, eroded, incomplete rim
Wall degradation	Terracing with many sharp-edged tiers, light rounding and slumping	Subdued terraces, smooth and rounded slumps, rim landslide deposits
Rim texture	Irregularly hummocky, short curved terraces	Hummocks are smoothed, superposed cratering

that are Eratosthenian age and older based on their absolute model age [11] (4 of 7 instances of available absolute model ages (AMAs) are over 3.2 Ga, which is widely accepted as the cap of Eratosthenian age classification) [12], but match the morphological profile for young, well-preserved complex craters without a bright ray system.

The crater set was further narrowed down using the following criteria: (1) classified as Eratosthenian craters [10], (2) sharp raised crater rim, (3) morphological identifiable continuous ejecta blanket extending one crater radius beyond crater rim, (4) slope of interior cavity wall close to the angle of repose (~30-35 degrees), (5) large hummocky flat floors, development of wall terraces, (6) presence of a central peak, (7) and occurrence of impact melt deposits [13]. These eliminations led to 52 total Eratosthenian craters, inclusive of possibly older craters (up to 3.9 Ga).

Craters were compared for freshness based on rim crest sharpness, wall degradation, and rim texture [14] to obtain classes A and B (Table 1), representing predominantly rugged and smooth morphology respectively (Figure 1). Classes A and B were then compared based on rim wall slope [15] and crater volume using Lunar Reconnaissance Orbiter Camera (LROC) Wide Angle Camera (WAC) Global Mosaic Digital Terrain Model (DTM) sampled at 400 m/pixel [16].

Results and Discussion: Crater volume increases as a power law of diameter as expected [17] ($R^2=0.9965$), however there is a difference in volume at the same diameter (ΔV) between the 2 classes, especially after ~80km diameter. The power exponent for class A craters ($0.204D^{2.515}$) is similar to fresher complex craters ($0.238D^{2.31}$) in an earlier work by Croft [17]. However, Croft's work does not exclude

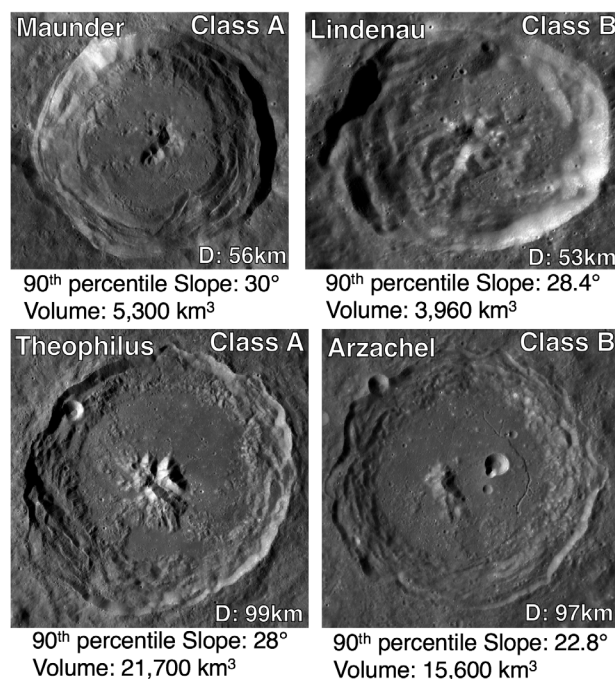


Figure 1: Examples of complex crater morphology freshness classification

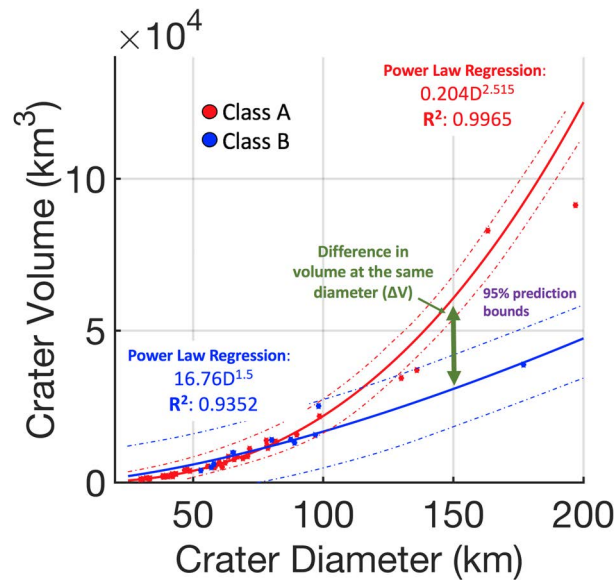


Figure 2: Volume and diameter power law regression of each complex crater.

Copernican craters and was for a different size range (19-150km; $n=21$). No strong trend was found in the craters' geologic context (highland or mare). The power law coefficient values also show that crater volume increases at a significantly lower rate than the cube of their diameters (as observed in simple craters [17]).

Rim wall slope values (90th percentile) vs. diameter show that the slopes increase with increasing diameter (Figure 3). The difference in the slopes of class A and B at the same diameter ($\Delta\theta$) (Figure 3) illustrates that the slope values are correlated with morphology at comparable diameter sizes (Figure 1), and especially for diameters over ~70km. Lower slope values appear to relate to bigger diameters, perhaps due to secondary impacting, slumps, and other crater weathering over time. This trend becomes ambiguous with craters smaller than ~75km in diameter, both in the volume and the slope studies.

It was shown in an earlier work, that the positive relationship between sharper slope values and AMAs roughly indicates the crater age for Copernican craters [15], and this data shows class A craters, which have fresher morphology, to have somewhat higher slopes. Low AMAs (shown in the graph) are typically associated with high slope values, even when separated by classes. Interestingly, the two class B values that are represented with an AMA (Figure 3) have the highest and lowest AMA values (Piccolomini and Vavilov craters respectively, indicated by a blue asterisk on graph). Though not as strongly correlated as values such as median slope value (Figure 3 inset), the 90th percentile shows a linear age trend that aligns with younger craters having higher rim slope values (higher slopes are often found closer to the rims).

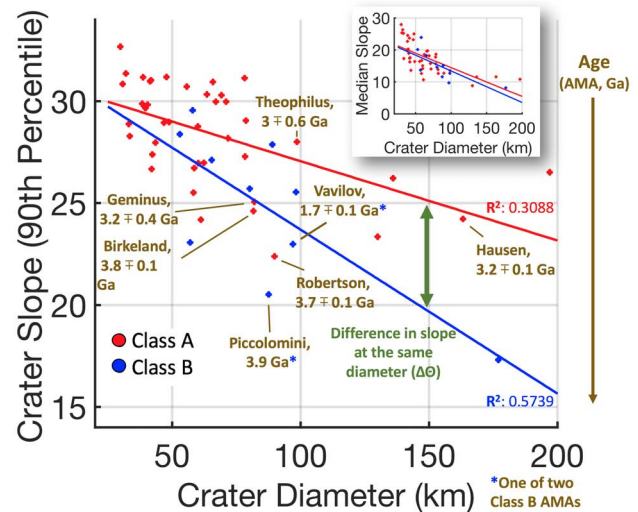


Figure 3: Slope (90th percentile) and diameter linear relationship of each complex crater.

Conclusion: In the absence of absolute model age (from crater counting), relative age (from maturity indicators, e.g. OMAT and rock abundance), and depth/diameter values (that may be used to categorize simple craters, but does not change with freshness in complex craters [18]), the morphological descriptors rim wall slope and volume can be used to classify between younger and older Eratosthenian craters. The (ΔV , $\Delta\theta$) pair appear to diverge more at larger diameters ($> 70\text{km}$), and the classification of craters smaller in diameter is more ambiguous. Our study shows that quantitative sub-classification of Eratosthenian craters based on morphology is challenging. Further analysis of complex craters shapes may provide better insights for freshness classification, and will be discussed in our future work.

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