QUANTITATIVE ANALYSIS OF LUNAR IMPACT CRATERS MORPHOLOGY. Ke Zhang[1,2,3] and Jianzhong Liu[1,3], [1]Center for Lunar and Planetary Science, Institute of Geochemistry, Chinese Academy of Sciences, 99 Lincheng West Road, Guiyang 550051, China, Email: zhangke415@mails.ucas.ac.cn . [2]University of Chinese Academy of Sciences, Beijing 100049, China. [3]Center for Excellence in Comparative Planetology, Chinese Academy of Sciences, Hefei 230031, China.

Introduction: Impact craters are the most common geological structural units on the moon, and can be divided into primary and secondary impact craters.

Primary impact craters are annular craters formed by alien celestial bodies hitting the lunar surface. Differences in impact conditions and target material can result in craters that cannot be shaped. Based on the formation mechanism of the impact crater and the magnitude of the impact energy, the impact crater is classified according to its morphological characteristics. They can are divided into five categories, including bowl craters, smooth floor craters, hummocky craters, terrance craters, and central peak craters (Figure 1).

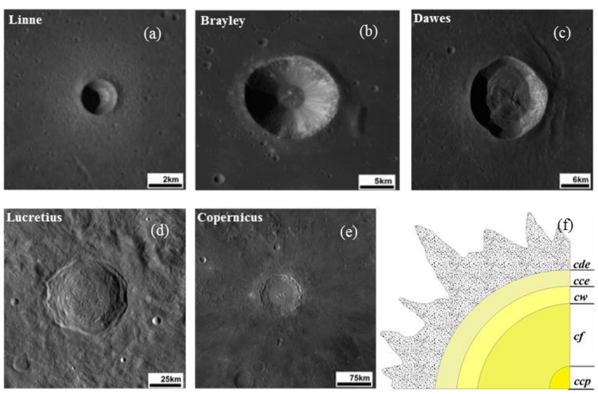

Figure. 1 Morphology characteristics of lunar impact craters. (a)Bowl crater; (b) Smooth floor crater; (c) Hummocky crater; (d) Terrance crater; (e) Central peak crater; and (f) The diagram of crater material classification and distribution (*ccp*: crater central peak; *cf*: crater floor; *cw*: crater wall; *cce*: crater continuous ejecta; *cde*: crater discontinuous ejecta).

The secondary crater is formed in the excavation stage of the impact crater. Due to the action of the sparse wave, the material in the target area is sputtered outward, and a large amount of material in the target area is ejected, and the ejected material re-impacts the surface of the moon under the gravity of the moon. Due to the differences in the projectile velocity, projectile angle, size and weight of the projectile fragments, the secondary craters formed also have different sizes and morphological characteristics, generally appearing as long and narrow, irregular, with a central mound. [1-2], shallower depths compared to primary craters of the same size, with secondary crater chains (such as herringbone-shaped secondary crater chains [3-4] and secondary crater clusters[5-6] (Figure 2).

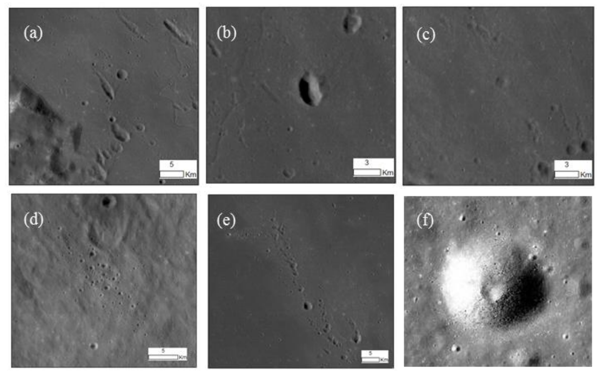

Figure. 2 Different morphology characteristics of lunar secondary craters. (a)Long and narrow secondary crater; (b) Irregularly shaped secondary crater; (c) Morphologically shallow secondary craters; (d) Clustered secondary craters; (e) Chained secondary craters; and (f) Secondary crater with central mound.

Among them, secondary craters with significant morphology (secondary crater chains and secondary crater clusters) are better identified, but it is more difficult to identify isolated secondary craters.

Data and Method: In this study, multi-resolution digital terrain models were used for multi-scale quantitative analysis, and digital terrain data of different resolutions were used to study geological characteristics, including the Lunar Reconnaissance Orbiter Camera Global Data with a resolution of 100m, Lunar Orbiter Wide Angle Camera (LROC WAC Empirical 7-Band Mosaic) and digital terrain data (LOLA DEM 29 pixels/degree). Among them, in order to more clearly identify the distribution range of secondary craters, the wide-view camera data of the lunar orbiter is used, which contains 7 bands (321nm, 415nm, 566nm, 604nm, 643nm, 689nm). The images of 3 different wavelengths were arbitrarily selected to be fused in Envi, and it was decided to synthesize false color at 566 nm (R), 411 nm (G), and 31 nm (31 nm) for this study.

By studying the morphological characteristics of the primary crater and the secondary crater, it can be known that the morphological differences between the two are mainly reflected in the depth, the shape of the crater edge and the height of the crater edge. In this paper, by studying the morphological characteristic parameters of the two, the identification index parameters are finally determined as irregularity, ellipticity, crater depth-diameter ratio, crater rim height and diameter ratio (table 1). Irregularity, that is, the ratio of the perimeter to the area of the impact crater is used to analyze the irregularity of the shape of the impact crater. When the Γ value is 1, the impact crater is a standard circle; the larger the *Γ*, the greater the irregularity of the impact crater. The ellipticity indicates how stretched the polygon is. When *ei* equal 1, it means a circle, and the larger the value of *ei*, the more complex the shape. The crater depth to diameter ratio is a parameter index used to analyze the depth of the impact crater by using the ratio of the depth from the edge of the crater to the floor of the crater and the diameter of the edge of the impact crater. The rim depth to diameter ratio represents the impact crater uplift height.

Table 1 Impact crater morphological index parameters

Morphological index	Usage	Formula
Irregularity	Analyze the degree of crater edge irregularities	$\Gamma = \frac{P}{2\sqrt{\pi A}}$
Ellipticity	The extent of the crater edge	$ei = \frac{\pi\ (L/2)^2}{A}$
Crater depth-diameter ratio	Analyze the depth of craters	$t = \frac{H}{D}$
Crater rim height-diameter ratio	crater edge uplift height	$y = \frac{h}{D}$

Note: *P* is secondary crater rim perimeter; *A* is secondary crater rim crest area; *L* is secondary crater max axis length; *H* is the depth of secondary rim crest to bottom; *D* is secondary crater rim crest diameter (the diameter of equal area circle as secondary crater diameter); *h* is rim crest height.

Result and Discussion: Calculate the different quantitative index parameters of the primary craters and the secondary craters, carry out repeated experiments to verify the range of each index parameter, and finally obtain the characteristic value of craters identification index parameter used in this study. For secondary craters, The irregularity is greater than 1.02, the ellipticity is greater than 1.2, the crater depth to diameter ratio is between 0.07 and 0.2, and the crater rim height to diameter ratio is between 0.02 and 0.04 (table 2).

Conclusion: Lunar craters form different craters (primary and secondary) due to different reasons for their formation. The secondary craters are formed due to the secondary impact of the ejecta material on the lunar surface when the primary craters are formed, so they are different in shape, resulting in different magnitudes in quantitative analysis.

Table 2 The eigenvalues of the index parameters for the shape recognition of the secondary craters

Morphological index	research scholar	Range of values	Range of values in this study
Irregularity	Zhou et al., 2015[7] Calef et al., 2009[8]	1.04~1.3 1.06±0.05	Γ≥1.02
Ellipticity	Guo et al., 2017[9] Nagumo and Nakamura, 2001[10]	~1.2 ≥1.2	ei≥1.2
Crater depth-diameter ratio	Moutsoulas and Preka, 1982[11] Basilevsky et al., 2017[12] Grant et al., 2006[13] Pike, 1976[14]	0.12~0.15 0.025~0.13 ~0.07 0.104~0.173±0.04	0.07≤t < 0.2
Crater rim height-diameter ratio	Watters, 2016[15] Pike, 1976[14] Pike, 1980[16]	0.03~0.04 0.02~0.04 ~0.02	0.02≤y≤0.04

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