DETECTING PRIMARY CRATERS AMONG CLUSTERS OF SECONDARIES.

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Introduction: Their occurence in clusters and chains (Fig.1) has traditionally been a major means of identifying secondary craters (e.g. [1,2]), and excluding them from counts of primary craters (e.g. [2]). However this practice risks excluding over-printed primary craters among the secondaries, particularly if other qualitative observational differences between primaries (e.g. sharp rims, bright ejecta and/or interiors, stipple-patterned ejecta, the presence of "blocks") and secondaries (irregular rims/interiors, "herringbone" ejecta) are not present. Crater depths and shapes provide another, more quantitative, means of ferreting secondary craters out of populations of primaries [1], or vice versa. All but the most agéd, heavily modified primaries tend to be deeper than secondaries, and also to have systematically different shapes (see below).

The effects of secondary cratering on crater-counting methods of estimating planetary surface ages have long been the source of much debate in planetary science. Central to this debate has been our ability (or lack thereof) to distinguish isolated secondaries from primaries. But what about distinguishing primaries from a background of secondaries?

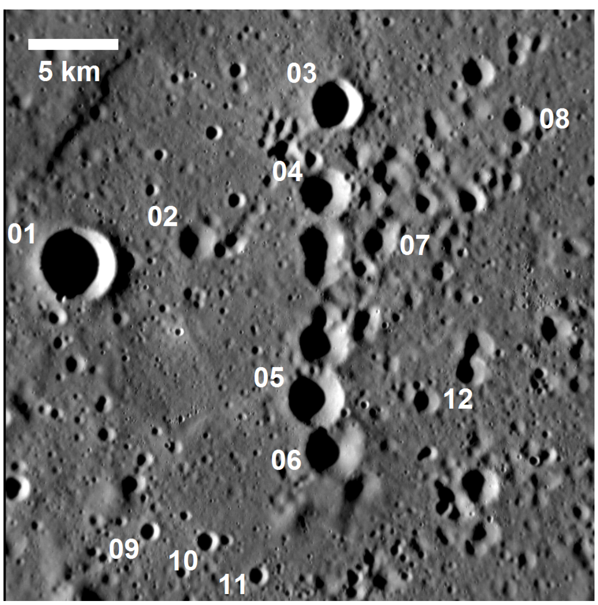

Figure. 1: MESSENGER image EN1033974656M (cropped). shows a cluster of secondaries located at 3.3°N 80.0°E. Crater 01 (left, D = 4.35 km) is an obvious primary and a chain of obvious secondaries runs N-S down the center of the image. Or so it would seem.

Methods: The recently developed Free Shadowfront Method (FSM) for measuring simple impact craters enables determination of the shapes and depths of these craters via the shapes and dimensions of the shadows cast within them [3,4]. It was applied to Mercury MESSENGER image EN1033974656M (Figs. 1 and 2), which covers the area of crater cluster centered about 3.3° N 80.0° E (Fig. 1). Twelve craters of interest and with shadows suitable for analysis with the FSM were identified, including 4 of the 7 largest (D = 2.5 - 3.5 km) craters in the cluster. These lie in a close N-S chain through the center of the image. A larger (D = 4.35 km) crater to the West is an obvious large primary. Upon qualitative inspection, 6 of these craters appear to be secondaries, one a clear primary, and 5 are of indeterminate type (Table 1, column 2).

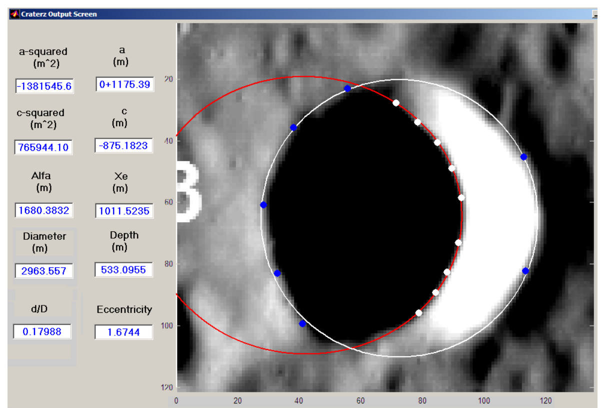

Figure 2: A screen shot of results for crater 07 showing the rim circle and shadowfront ellipse

Results:

Crater 01 - Based upon its large diameter, conspicuously sharp near-circular rim, and long shadow (indicating greater depth), 01 appears to be a primary crater (Table 1, column 2). Its high d/D (0.24) and low eccentricity (e = 1.74) are quite consistent with fresh primary craters on the Moon (Fig. 3; [4,5]), and thus serve to confirm (Table 1, column 7) the initial identification.

Craters 04-08 - These craters all lie within the main crater cluster (3 within the "main chain"), display significant irregularities, and have softer rims and cast shorter shadows than crater 01. They were therefore pre-identified as secondaries. Measurements of their depths and shapes confirmed these diagnoses (Table 1; Fig. 3): 04 - 08 are almost certainly secondaries.

Craters 02&12 - Though they lie outside of the crater cluster proper, qualitatively these craters appear to be secondaries; their measurements are fully consistent with this observation.

Craters 09-11 - These craters also lie outside the main cluster. They are too small for much detail to show, however they appear unusually similar, suggesting that they may be related, possibly secondaries. Quantitative measurements confirm their physical similarity - but also strongly indicate that they are unrelated primaries.

Crater 03 - Like 04 - 08, this crater lies within the crater cluster, and is a member of the main secondary chain, and also displays minor irregularity about the rim (Fig. 2). However its *d*/*D* and *e* measurements clearly indicate that this is a *primary* and not a secondary impact crater.

Conclusion: Using the usual observational methods, this cluster of apparent secondary impact craters contains at least one primary crater that would likely be excluded from any survey of primaries. Thus inclusion of secondaries in counts of primary impact craters is not the only way the presence of secondaries may affect crater counting methods: Exclusion of some actual primaries may also occur.

References: [1] Wilhelms D.E. et al. (1987) The Geologic History of the Moon. [2] McEwen et al. (2006) *Ann. Rev. Earth & Planet. Sci.*, *34*, 535-567. [3] Chappelow J.E. (2013) *Meteoritic & Planet. Sci., 48,* 1863-1872. [4] Chappelow J.E. (2018) *Meteoritics & Planet. Sci., forthcoming*. [5] Chappelow J.E. (2015) *46th LPSC*, Abst# 1079.

Table 1: Results of FSM measurements of the 12 craters numbered in Fig. 1.

Crater#	Type?	Lat	Long	ecc	d/D	TYPE	Notes/Comments
01	Prime	3.42	79.65	1.742	0.236	Prime	An obvious probable primary
02	????	3.45	79.82	3.001	0.109	Sec'd	
03	Sec'd	3.63	80.00	1.674	0.180	Prime!	This one is a hidden primary!
04	Sec'd	3.50	79.98	3.046	0.137	Sec'd	
05	Sec'd	3.23	79.98	3.012	0.156	Sec'd	Here d/D is not definitive, eccentricity is
06	Sec'd	3.15	80.00	2.248	0.117	Sec'd	
07	Sec'd	3.44	80.06	3.028	0.117	Sec'd	
08	Sec'd	3.59	80.24	2.111	0.106	Sec'd	Here eccentricity is not definitive, d/D is
09	????	3.05	79.76	1.245	0.141	Prime	
10	????	3.04	79.84	1.525	0.142	Prime	
11	????	3.00	79.91	1.327	0.143	Prime	
12	????	3.20	80.10	2.491	0.122	Sec'd	

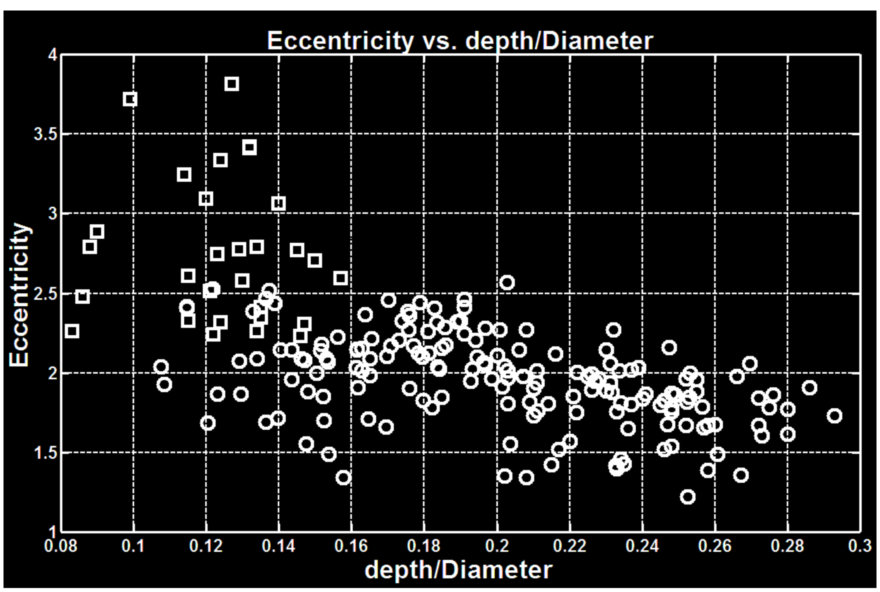

Figure 3: A plot of eccentricity vs. *d*/*D* for 29 recently collected lunar secondary craters (squares) over the simple crater data used in [3] and [4] (circles). Note that the secondaries cluster toward shallower *d*/*D* and higher *e* values.