EXAMINING DOUBLET CRATERS ON THE LUNAR MARIA TO CONSTRAIN BINARY ASTEROIDS IN THE NEAR- EARTH POPULATION P. F. Wren and R. A. Fevig

Introduction: A doublet is a pair of impact craters created by the same primary impact event [1]. Doublet craters have been observed on Earth, the Moon, Mercury, Venus, Mars, Ceres, and Vesta [2,3,4,5,6,7,8,16,17].

Doublet crater formation. Originally, doublet crater formation was attributed to a single impactor broken up by either atmospheric disruption [9] or tidal forces [1,10], but further studies showed these processes could not result in sufficient separation to create the observed doublets [11,12]. It is now believed that well-separated binary asteroids are the source of doublet craters [12]. This makes doublets a source of evidence for the prevalence of binary asteroid systems.

Constraining binary asteroids. The percentage of asteroids in the current near-earth population that are binary is fairly well established at 15% [2,18]. A systematic study of doublet craters on the Moon could provide insight into the (1) size of the components of NEA binaries, (2) frequency of impact, and (3) percentage of NEA binaries since the formation of the regions of interest.

Methods and Data: Desiring lightly-cratered units for this study to avoid crater saturation, as well as homogenous areas of uniform age, we initially considered several maria. Concerned with minimizing secondary craters, we also gave consideration to a region’s proximity to larger post-mare impacts. Using Wilhelms’ geologic map of the Moon [18], we eliminated Mare Imbrium and Oceanus Procellarum for their proximity to the large craters Copernicus, Kepler, and Aristarchus. Mare Nubium was eliminated due to its lack of uniform geologic age. Our final candidate survey areas are Mare Serenitatis, Mare Tranquillitatis, Mare Fecunditatis, Mare Humorum, and Mare Crisium.

Visual evaluation of crater pairs. For convenience, we are defining search areas whose boundaries align with lines of longitude and latitude (e.g. Figure 1). In JMARS [13], we use Robbins’ global database of Lunar craters [19] to locate all impact craters smaller than 500 km in diameter. Pairs of craters in close proximity are considered potential doublets. Following the same process as our previous work [14,16,17], these crater pairs are examined in LROC NAC images [20] and evaluated using our scoring system.

Monte carlo simulation. A Monte Carlo simulation will be used to create randomly-distributed impact points within each study region. Separations between all unique pairs of random impacts are computed as great-circle distances. These are tallied to produce a distribution we would expect if impactors were single bodies, and their impact locations are due solely to chance.

Results: We have completed the initial data collection for all five maria. This includes the identification and location of all craters in the search area, and the determination of all crater pairs that have the potential to be doublets (see Table 1).

A total of 1,103 pairs of craters were identified across all five areas using a Python program. The algorithm selected pairs of craters whose centers are separated by a distance that is equal to or below their combined radii (i.e., their rims either touch or overlap). These pairs are the most likely to exhibit conclusive evidence for a binary impact.

Table 1: Study areas

<table>
<thead>
<tr>
<th>Mare</th>
<th>Area (km²)</th>
<th>Number of Craters</th>
<th>Candidate Pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tranquillitatis</td>
<td>223,000</td>
<td>1,895</td>
<td>214</td>
</tr>
<tr>
<td>Serenitatis</td>
<td>212,850</td>
<td>801</td>
<td>41</td>
</tr>
<tr>
<td>Fecunditatis</td>
<td>149,313</td>
<td>2,434</td>
<td>795</td>
</tr>
<tr>
<td>Humorum</td>
<td>80,647</td>
<td>395</td>
<td>21</td>
</tr>
<tr>
<td>Crisium</td>
<td>95,019</td>
<td>470</td>
<td>32</td>
</tr>
<tr>
<td><strong>totals</strong></td>
<td><strong>760,829</strong></td>
<td><strong>5,995</strong></td>
<td><strong>1,103</strong></td>
</tr>
</tbody>
</table>

Thus far, we have analyzed crater pairs from Mare Crisium, Mare Humorum, and Mare Serenitatis. Within the combined areas totaling 388,500 km², we
examined 94 candidate crater pairs. A number of pairs received scores greater than zero, and we are in the process of taking a more critical look at some of these. Among those that merit a closer look, a few will clearly be considered possible or likely doublets according to our methods of vetting (see Figures 2 and 3 for examples).

We are currently working to apply morphologically-based techniques that would examine

- Crater depth/diameter ratio
- Asymmetric crater excavation

to help us remove crater pairs from consideration that contain secondaries or that are coincidental.

We anticipate completion of the visual inspection and scoring of craters from all study areas prior to the 11th Planetary Crater Consortium Meeting.

**References:**


**Continuing Work:** The bulk of our remaining work is the visual inspection and scoring of crater pairs from Mare Tranquillitatis and Mare Fecunditatis.

We are also concerned with false positives. Secondary impact craters would increase the number of candidate crater pairs, since they cluster in proximity to one another. Secondaries also often form pairs [15], mimicking primary doublet impacts. Another source of false positives are coincidental impacts, i.e., two separate impact events resulting in craters whose rims are close or even touch.

**Preliminary Conclusion:** After visually inspecting a small fraction of more than 1,000 candidate crater pairs in the combined study area, we found multiple doublets. These early results give us confidence that we can successfully analyze the remaining two maria and derive the same type of statistics we previously produced for Ceres and Vesta [14,16,17].