COMPARING SMALL MAIN BELT BINARY ASTEROIDS OF THE INNER AND INTERMEDIATE ZONES USING DOUBLET CRATERS ON VESTA AND CERES. P. F. Wren[1] and R. A. Fevig[2], [1]Mars Space Flight Facility, School of Earth and Space Exploration, Arizona State University, 201 Orange Mall, Tempe, AZ 85287 [2]Department of Space Studies, University of North Dakota, Clifford Hall Room 512, 4149 University Ave Stop 9008, Grand Forks, ND, 58202 paul.wren@asu.edu

Introduction: A doublet is a pair of impact craters created by the same primary impact event [1]. Doublets have been observed on Earth, the Moon, Mercury, Venus, Mars, Ceres [2,3,4,5,6,7,8,19], and now we report on the first doublet craters observed on 4 Vesta.

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 asteroid populations. The percentage of asteroids in the near-earth population that are binary is fairly well established at 15%, and doublet craters on Mars, Earth, Venus, and the Moon have been used to confirm this value [2,18]. 144 binary asteroids have been identified in the main belt using ground-based and spacecraft observations [13], but smaller binary systems have likely gone undetected. In a previous study, images of Ceres taken by the Dawn spacecraft were analyzed for the presence of doublet craters [19,20]. These impact features provide evidence for the size and abundance of binary asteroid systems in the main belt, down to smaller diameters than previously possible.

Comparing inner and intermediate zones. The Main Asteroid Belt is divided by the most prominent Kirkwood gaps into three zones: Inner, Intermediate, and Outer [25]. 1 Ceres orbits in the intermediate zone, while 4 Vesta occupies the inner zone. Similar to the previous Ceres study [19,20], this study will use Dawn Framing Camera images of Vesta [15] to search for doublet craters. These results will be compared to data from the Ceres study to determine if differences exist between the inner and intermediate zones of the Main Belt.

Data and Methods: Inspired by Melosh, Ingram, and Bottke [8], the previous Ceres research [19,20] adopted a similar data collection and analysis approach. This study will use the same methods for Vesta. The study region is bounded by 50°E to 110°E and 20°N to 20°S, roughly 55,000 km^2. Using JMARS [17], we will count impact craters ≥ 3 km appearing in Dawn Framing Camera images from this region captured during the Low Altitude Mapping Orbit (LAMO) [14]. Craters separated by less than 20 kilometers will be considered potential doublets and evaluated using our scoring system. Points are added for similar erosion, as well as for possible ejecta lobes or a septum. Points are subtracted for superposition, or for obvious differences in erosion or crater depth.

Impactor sizes will be estimated using a crater scaling law originally created for simple impact craters found on outer solar system moons [22]. This crater scaling formula depends on the following inputs: The diameter of the impact crater, the impactor's velocity and density, the density of the target's crust, and the gravity of the target body. The values for Vesta's crustal density and gravity are known [23,24], but estimates are required for the impactor density and velocity. A study by Bottke et al. [26] determined that the highest-probability collisional velocity for Main Belt asteroids was 4.4 km/s. In our previous study [20], we used Carry's review of known densities for small solar system bodies [27] to compile a list of 138 stony main belt asteroids. Their mean density is 2.788 g/cm^3.

Table 1: Candidates for Doublets in Vesta in Study Area

Crater Pair	*Longitude*	*Latitude*	*Diameter (km)*	*Separation (km)*	*Impactor Diam (m)*	*Doublet?*
Pair 1	90.500	17.016	3.8	1.87	255	Very likely
	90.703	17.375	3.0		189	
Pair 2	98.557	-18.566	3.7	2.32	247	Likely
	98.192	-18.934	4.5		317	
Pair 3	91.169	-8.560	3.2	2.15	205	Possible
	91.609	-8.734	3.2		205	
Pair 4	57.094	18.703	4.3	4.55	299	Possible
	58.141	18.766	4.4		308	

Results: 289 craters ≥ 3 km were counted in our study region. 1100 pairings separated by < 20 km are considered potential doublets.

Visual evaluation. We are visually inspecting all potential doublets, evaluating them using our scoring system. After examining only a portion of these pairs, we have identified four crater pairs that are possible doublets (Table 1). Figure 1 shows Pair 1, an excellent example of a doublet crater featuring both a septum and ejecta lobes.

Estimating impactor size. We used the crater scaling law mentioned above to estimate the diameter of the

impactors that created our likely doublet craters on Vesta (see Table 1 for impactor diameters in meters).

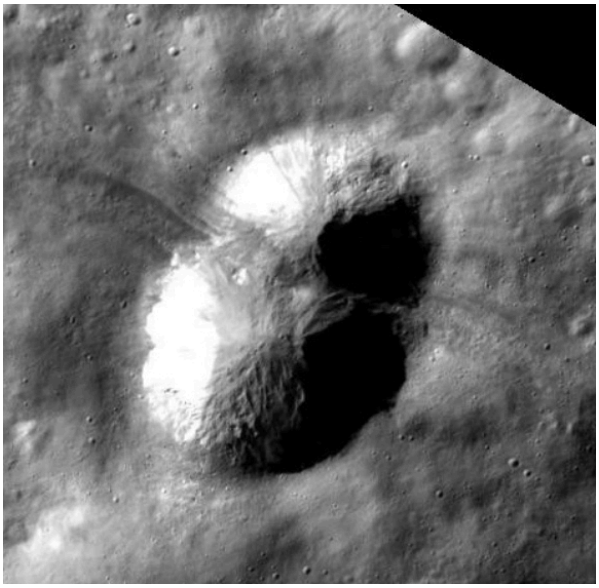

Figure 1: "Pair 1", a very likely doublet crater from Dawn Framing Camera image FC0024266 [15].

Preliminary Comparisons: If Pairs 1 through 4 are true doublets, our work so far places a lower bound on the percentage of doublet craters in this region of Vesta at 1.4% (4 out of 285 impact events), somewhat below the current estimate of 2-3% for both Earth and Mars [2]. How does this percentage, and the average calculated impactor diameter of 253 meters, compare with Ceres? In the previous study [20], only 0.7% of impact events on Ceres were identified as doublet craters. Our preliminary observations of craters on Vesta show a value 2x that of Ceres. 1.4% implies at least 9.3% of the asteroids in the Inner zone are binary systems (only 15% of binary asteroids create a visible doublet [2,8]).

Table 2: Doublet craters: Ceres vs. Vesta

	1 CERES	4 VESTA
Semi-major axis:	2.77 AU	2.36 AU
Main Belt zone:	Intermediate	Inner
Doublet craters:	0.7%	1.4%
Mean Impactor Diameter:	247 m	253 m

Table 2 shows that the binary asteroid impactors that created doublet craters on Vesta in the Inner zone were quite similar in average diameter to the binary asteroids encountered by Ceres in the Intermediate zone [20]. Aside from the crater diameter and the gravitational acceleration of Vesta, the remaining values in the crater scaling law are estimated or averaged values. The small difference seen is likely within the margin of error.

Continuing Work: The remainder of the crater pairs will be evaluated, which may yield additional doublet craters. We also plan to calculate error bounds for the impactor diameter calculations. We will report our findings at the 50th LPSC in March.

Future Work: We are also interested in pursuing other questions related to this work:

- What are the possible sources of the different doublet crater abundances on Vesta and Ceres?
- How does the percentage of doublet craters at the poles of Vesta compare to those near the equator?
- Given the low gravity of Vesta, do secondary craters, which often appear as doublets [21], exist?

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