DIFFERENCES IN TRANSITIONAL CRATER MORPHOLOGIES AS A FUNCTION OF IMPACTOR PROPERTIES. E. A. Silber[1] , G. R. Osinski[1,2] and R. A. F. Grieve[2], [1]Centre for Planetary Science & Exploration / Department of Physics and Astronomy, University of Western Ontario, London, ON, N6A 3K7, Canada, [2]Department of Earth Science, University of Western Ontario, London, ON, N6A 5B7, Canada (esilber@uwo.ca)

Introduction: Impact craters, one of the most persistent geological features on solid planetary bodies, are the aftermath of cosmic collisions. Impact craters are typically classified into two main categories: (i) simple, bowl-shaped craters, and (ii) complex crater structures, which include central peak, central-peak basins and peak-ring basins [1]. As craters transition from simple to complex structures [2,3], another subgroup, dubbed "transitional" craters, appears. Transitional craters cannot be classified as either simple or complex, because their morphologies tend to differ from both (e.g. flat crater floors, but no visible central uplift) [2]. On the Moon, the transition occurs at ~19 km [2]; however, a significant variation in crater diameters (15-42 km) [3] and depths (2-5 km) [4] have been observed. While target properties have been generally considered as the primary factor in the observed differences [2], the role of the impactor (e.g., size, velocity) cannot be neglected.

Scaling laws are used to predict the crater diameter as a function of impactor (projectile) and target properties, such as the impact velocity, impactor size and density, gravity, target density and a range of material properties (e.g., the coefficient of friction, cohesion, etc.) [5]. Experimental and theoretical studies, along with numerical modeling, are used to derive and refine scaling laws [5,6]. One of the theoretical considerations is a point source approximation [7,8], where the so-called coupling parameter (C) characterizes the coupling of impactor energy and momentum into the target material, and is a function of the impactor diameter (D_i), velocity (V_i) and density (ρ):

$$C = D_i V_i^{\mu} \rho^{\nu} \qquad (1)$$

Although the coupling parameter can take values anywhere between the energy (μ=2/3, ν=1/3) and momentum (μ=1/3, ν=1/3) regimes, in reality, it is somewhere in-between [6,8].

In principle, in far-field, all impacts with equal C will produce same-sized craters. Thus, the inevitable question arises: could the observed morphological differences in part be attributed to impact scenarios where the projectile is fast and small vs. slow and large? In this study, we use numerical modeling to investigate the role and effect of impactor properties (in terms of energy and momentum delivery), given some coupling parameter C, on crater morphology and temporal evolution, with a focus on transitional lunar craters.

Methodology: We ran a series of simulations using iSALE-2D, a multi-material, multi-rheology shock physics hydrocode [9,10]. Due to the axial symmetry of the 2D model, only vertical impacts were considered. We used the ANEOS equation of state for granite [11] to represent the lunar crust, and dunite [12], as it is a good approximation for typical asteroidal material (ordinary chondrite), to represent the impactor. The effect of acoustic fluidization [13] was also taken into consideration. The grid resolution for the initial suite of runs shown here was set to 10 cells per projectile radius (CPPR). The two parameters varied throughout all simulations were the impactor velocity and diameter, as these are the required parameters for producing the same size crater given some coupling parameter C. The target properties were kept constant. To account for a wide range of lunar impact velocities [14], we set the range from very low values (6 km/s) up to the maximum of 23 km/s, with additional increments at 10 km/s, 15 km/s and 17 km/s. The impactor size was determined in two ways; first, through test simulations which we used to define μ, and second, through eq. (1) once μ was known. To establish the value of μ in eq. (1), given our simulation specific material inputs, we first ran a number of test simulations. From these, we calculated μ = ~0.56. We subsequently ran a series of sets of simulations, producing simple, transitional and complex craters, from 5 km up to 40 km in diameter. Each set consisted of a combination of impact velocities and impactor diameters such that they yield the same coupling parameter. A set of representative simulations with the same coupling parameter (C = 7.35E4) are shown in Table 1.

Table 1: The parameters for one set of simulations, corresponding to the final crater diameter of ~16 km.

Sim #	Impact Velocity (km/s)	Impactor Diameter (m)	Cell size (x,y) (m)
8015	6	1790	89.5
8016	10	1342	67.1
8017	15	1067	53.4
8018	17	994	49.7
8019	23	839	42

Results: Fig. 1 shows one set of simulations (Table 1) corresponding to a crater of 16 km in diameter, as measured at the pre-impact level. The crater temporal evolution, as well as morphology, varies as a function of the impactor size/velocity combination, especially in the transitional crater regime. Although the differences might appear subtle as the impact velocity gradually increases and the impactor size decreases, they are quite noticeable at far ends of the spectrum (slow/large vs. fast/small impactor). In particular, our simulations suggest that transitional craters exhibit the greatest variation in crater depth, compared to complex (or borderline complex craters). For example, 300 seconds after the impact, the crater depth is 1.5 km in simulation #8015 and nearly 4 km in simulation #8019.

Furthermore, we found a "sweet spot", whereby a slow/large impactor will produce a transitional/borderline complex crater, while a fast/small impactor will result in a purely transitional crater (flat floor). In near-complex craters, the amount of uplift is found to vary as a function of impactor size and velocity.

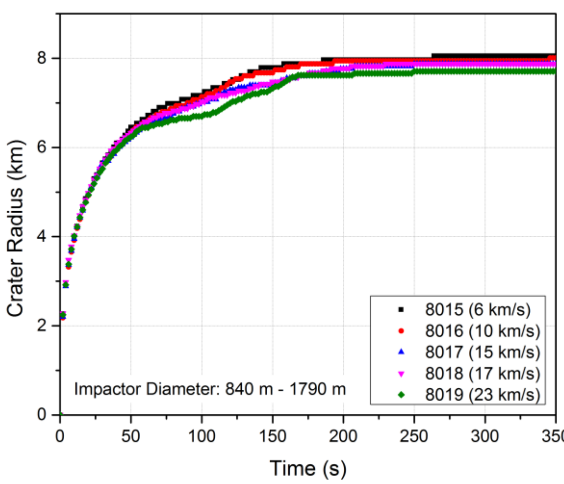

Figure 1: (a) The crater radius vs. time. The impactor size and velocity for each simulation are listed in Table 1. The final crater radius is ~8 km (diameter = 16 km).

Summary and Future Work: Through a series of simulations, we have modeled craters with final diameters, as measured at the pre-impact level, ranging from 5 km to ~40 km (simple, transitional, and complex craters). Although each set of simulations with some coupling parameter *C* produced a crater with the same final diameter, the morphological differences within the set were evident, especially in the transitional crater size. Therefore, the importance of impactor size and velocity are not negligible and might account for some of the observed morphological differences in transitional lunar craters.

To further refine the results presented here, we are running a suite of high resolution simulations. The next step in our study is to investigate and quantify the volume of melt as a function of impactor size and velocity as it applies to transitional lunar craters.

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