CLATHRATE CRATER PROFILES: IMPACT MODELING IN CLATHRATE-RICH LOCATIONS.

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Introduction: Clathrate hydrates are composed of a crystalline water ice structure enclosing molecules of a guest gas. Though clathrates are assumed to be common throughout the solar system, it is difficult to identify clathrate hydrates since these materials are often indistinguishable from less orderly mixtures of water ice and guest gas molecules using remote sensing techniques. Saturn's moon Titan is a promising location for methane clathrate detection. The Titan environment is rich in clathrate materials, with water ice and hydrocarbons in abundance [1]. Crater morphology might be a useful tool for differentiating clathrate-rich locations from water ice. Clathrates exhibit a few unique material properties relevant to impact. While in many ways methane clathrate behaves identically to water ice, some thermal and rheological characteristics are significantly dissimilar [1]. These properties could change the impact cratering process enough to produce altered crater morphology.

The Cassini mission's synthetic-aperture radar (SAR) identified 44 possible craters and 5 confirmed craters [3]. Some circular Titan geomorphological features have been tentatively classified as craters. Wood et al. describe these atypical craters as having more jagged, bulky rims than typical craters, which are usually identified by circular shapes with radar-bright rims and central peak features indicating rough terrain and smooth radar-dark basin floors [3]. We hypothesize that clathrates present in the target surface could be responsible for this alteration from more typical morphology. Therefore, the objective of our study is to model the impact process into a clathrate-rich surface to see if we can reproduce these unusual features

Methods: To model the formation of craters made in clathrate materials we used the iSALE-Dellen shock physics program, with relevant updates and modifications [4, 5, 6, 7, 8]. This Linux-platform program simulates impact cratering events, allowing the user to choose the desired materials for both impactor and target surface. PySALEPlot was then utilized to visualize the results of each model. Each output crater pair was measured for the following four characteristics: crater width (CW), crater depth (CD), rim height (RH), and rim thickness (RT).

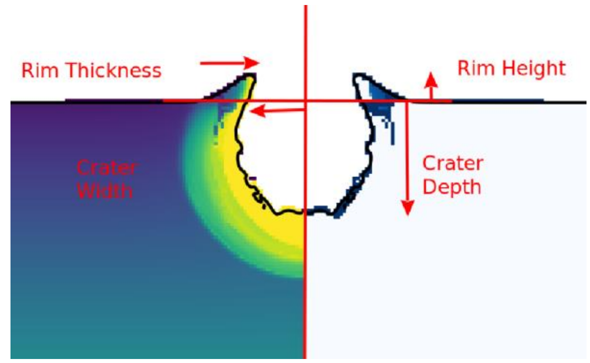

Figure 1: Crater measurements. Each crater's width (CW) and depth (CD) were catalogued, along with rim height (RH) and thickness (RT). All measurements relative to pixel size.

Four scenarios were explored: 1.6 and 10 km spherical water ice impactors with 10.5 km/s impact velocity. These values were chosen based on estimated average impact velocity, the smallest impactor that could reach Titan's surface unhindered by the thick atmosphere and the estimated size of impactor that produced Titan's largest confirmed crater, Menrva [1, 2]. Each size impactor was then modeled two times, first striking a water ice target and second striking a clathrate target.

iSALE was set to recreate Titan conditions: 90 K surface temperature, 1.352 m/s^2 gravitational acceleration, 5,149.5 km diameter. The thermal gradient used was 10 K per km of depth beneath Titan's surface. Water ice equations of state were supplied by iSALE's ANEOS routine. Methane clathrate material properties were based on Wakita et al., using methane clathrate values for thermal softening, cohesion and limiting strength to calculate equations of state [1]. All other parameters used for methane clathrate were identical to water ice.

Results: Figure 3 shows the 1.6 km impactor at t = 1.52 seconds after impact onto water ice (top) and methane clathrate (bottom). The excavated volume for both types of ice is nearly identical. However, there are subtle differences in the crater floor, with the methane clathrate crater having a rounder crater bottom and more jagged surface compared to the crater in water ice, which shows a smoother inner surface and a slight depression at the lowest point.

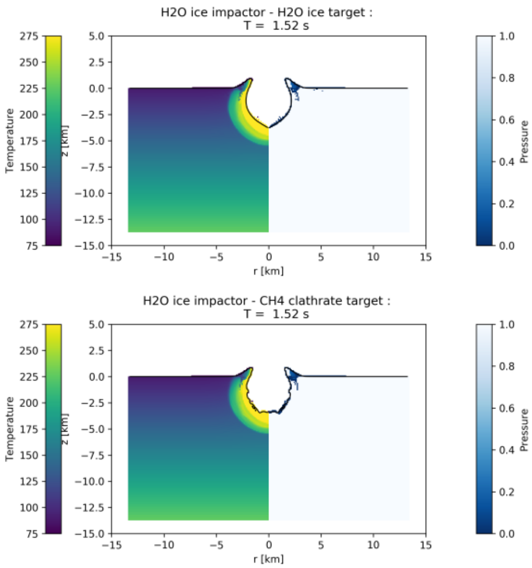

Figure 2: (Top) 1.6 km spherical water ice impactor on a water ice surface. (Bottom) 1.6 km spherical water ice impactor on a methane clathrate surface.

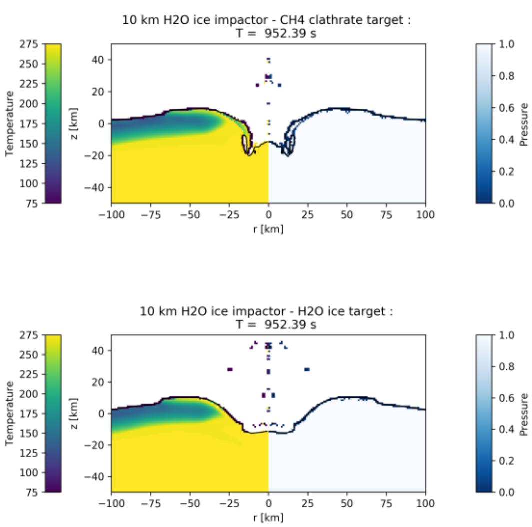

Figure 3: (Top) 10 km spherical water ice impactor on water ice target surface. (Bottom) 10 km spherical water ice impactor on methane clathrate target surface.

Figure 3 shows results for the same scenarios with a 10 km impactor at t = 952.39 s post-collision. The crater in water ice (Top) is shallower, with sloping sides and a nearly flat floor. By contrast, the crater in methane clathrate (Bottom) has steeper sides, a pronounced central peak, and what appear to be voids at the perimeter of the crater floor.

Measurements were made of each crater as described in Figure 1 and collected in the following table, including the CW/CD ratio:

Impactor Size Target Surface	**CW**	**CD**	**RH**	**RT**	**CW/CD**
1.6 km H2O	93	164	42	62	0.56707
1.6 km Clathrate	91	146	37	141	0.62329
10 km H2O	166	86	69	487	1.93023
10 km Clathrate	93	130	66	561	0.71538

The CW/CD ratio value is very close for smaller craters, but less so for larger ones. A crater produced by a 10 km impactor has very shallow walls, one produced by an identical impactor in clathrate has much steeper walls. Craters in clathrates also appear more likely to show a central uplifted peak than those in water ice.

Conclusions: Crater morphology studies may be useful to help determine ice composition of icy solar system bodies. Differences in wall slope, the presence of a central peak, and the ratio between diameter and depth could help distinguish between craters in water ice and those in methane clathrate.

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