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Fluvial erosion of impact craters on Titan

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Abstract

Titan's surface shows significant evidence of extensive fluvial modification. We suggest that fluvial erosion is responsible for the significant lack of craters, as well as the lack of central peaks in the few complex craters observed. Using a drainage basin model, we present a comparison of the efficiency of erosion and infilling of craters of varying size on Titan's surface, and estimate the timescale on which those craters may be erased.

1. Introduction

Titan is the only satellite in the solar system where stable liquids exist on its surface. Meteorological phenomena have been monitored on Titan by Cassini, revealing frequent clouds [6] and ample evidence of rainfall [7]. The low latitudes are covered with extensive networks of dendritic fluvial channels [3], and the Huygens probe landed in what appeared to be a dry flow bed, indicating extensive erosion by fluvial processes.

The presence of active fluvial processes is also suggested by the dearth of impact craters on Titan, which indicates a young, heavily modified surface. All craters on Titan are expected to be larger than the simple to complex transition diameter due to the effects of the atmosphere. This suggests that all observed craters should have central peaks; however, many do not plainly exhibit this feature and appear to be fluvially modified. Sinlap crater (112 km diameter), one of the best imaged, shows obvious fluvial erosional signatures and has a radar-bright central area that may be interpreted as the remains of an eroded central peak [5]. Studies of erosion rates on Titan [1, 2] indicate similar, but slightly higher, efficiencies relative to Earth due to differences in the body's composition (liquid methane and water ice, rather than liquid water and rock), and to Titan's lower gravity.

Erosion efficacy is controlled by several factors, including precipitation rates, soil production, relief, and material type, which are all poorly constrained for Titan. In contrast, the size of Titan's craters are well determined and these structures form drainage basins. Basin size has a strong influence on channel erosion efficiency. Small drainage basins show remarkably higher sediment yields than larger basins as they typically have very steep slopes, causing higher-gradient stream channels and more effective colluvial transport. As a basin expands, the floodplain area also increases leading large basins to have lower average slopes, as well as a greater opportunity to deposit and store sediment before reaching the valley floor. Also, drainage density (number of streams) will always remain high near a divide, but may decrease towards the central part of the basin.

In this study, we model fluvial modification of Titan craters through channel erosion using a drainage basin model. We demonstrate the decrease in erosion efficacy with increased basin size. Impact cratering rates are not well constrained for Titan, but still allow us to make an estimate on the lower limit of crater diameter expected to survive to present day, and determine if fluvial erosion can be responsible for the lack of craters on Titan's surface.

2. Drainage Basin Model

We use the model developed by Howard (1994) [4] to model erosion and sediment transport in a crater. The model has three components: slopewash and colluvial transport, alluvial channel erosion, and non-alluvial channel erosion. The slopewash and colluvial component characterizes how much sediment is eroded from precipitation and moved via creep or avalanching. The non-alluvial erosion component characterizes erosion through mechanisms such as plucking and cavitation, and transport of sediment in the flow. The alluvial component characterizes erosion through abrasion, transport in the flow, and deposition downstream. The primary variable controlling the model is slope, though there are several constants that affect erosion efficiency, such as erodability factors and critical stresses. Values for these constants are estimated based on values from terrestrial studies in desert environments [4] and studies of comparative erosion rates between Earth and Titan [1, 2].

2. Preliminary Results

We ran the model using a HiRISE digital elevation model (DEM) of a crater (~200m in diameter) as the initial input topography. This crater is much smaller than what has been observed on Titan, but illustrates the efficiency and effects of fluvial erosion over time. Figure 1 shows a cross section through the center of the crater filling in over a period of 500 kyr. The crater depth has decreased by ~30m, the crater diameter has increased, and the floor has flattened.

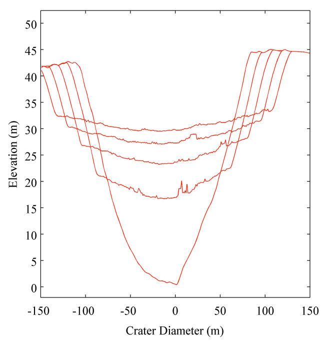

Figure 1: Cross section of a crater filling in over a period of 500 kyrs.

We then ran the model on a larger crater, ~200 km in diameter, using the same DEM but with a lower D/h ratio. Figure 2 (top) shows the initial crater topography and (bottom) the topography after 500 kyrs. There is significant ponding of sediment in the crater center, even though the level of infilling appears low. In this case, the crater has infilled ~4% (by depth), compared to the ~70% of the smaller crater.

6. Summary

Our preliminary model results indicate that fluvial erosion is effective in transporting significant amounts of sediment in both large and small craters on timescales of 10^5 years. They also suggest that these processes can erode away craters, enlarge their diameters, and create flat, smooth floors, in good agreement with observations. We will present a comparison of the efficiency of erosion and infilling of craters of varying size on Titan's surface. We will also estimate the timescale on which craters of those sizes may be erased by fluvial processes, as well as estimate the relative ages of specific craters on Titan.

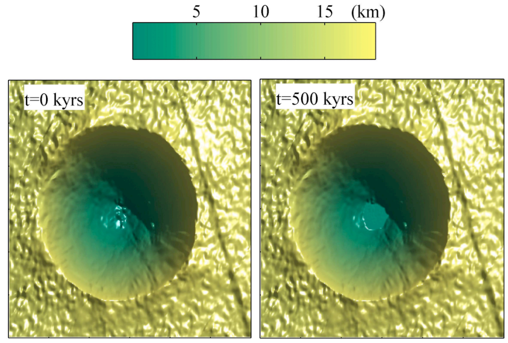

Figure 2: Initial topography (top) and topography after 500 kyrs (bottom).

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