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Landslides triggered by impacts on asteroid (21) Lutetia?

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1. Introduction

On 10 July 2010 the Rosetta spacecraft approached the main belt asteroid 21 Lutetia at a distance of 3170 km. The Optical, Spectroscopic, and Infrared Remote Imaging System (OSIRIS) on board of Rosetta [1] took 462 images covering more than 50% of Lutetia's surface with a maximum resolution of 60 m/px.

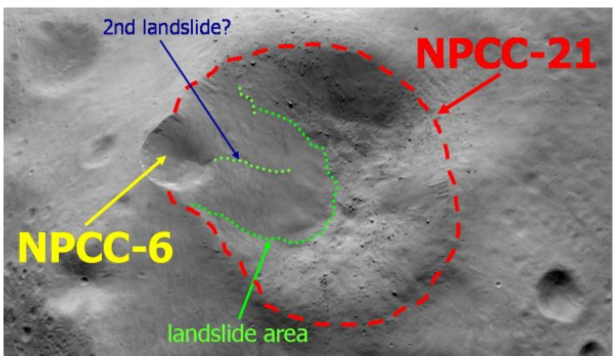

Figure 1 Main features within the fresh 21 km crater NPCC-21.

Images from the North Pole Craters Cluster (NPCC) of the Baetica region show large topographical slope variations (from 0 to 45 degrees) and reveal evidence for major modification processes, such as landslides [2]. This region locates one of Lutetia's largest craters with a diameter of 21 [3] to 24 km [4], named NPCC-21 hereafter (see Fig. 1). The crater appears to be relatively young. Boulders sized up to 300 m are visible inside the cavity and along the rim [3,5]. The regolith layer is estimated up to several hundred meters in thickness [5-7] and at least one large landslide occurred at the crater rim [3]. A small 6-km-diameter structure (named NPCC-6 hereafter) is located at the rim of NPCC-21 that most likely originates from another impact [3]. The location of the crater at the top of the landslide area suggests that this impact event may have triggered the landslide. It is still uncertain, whether the asymmetric shape of NPCC-6 is due to topography or the landslide event. The example may serve as an excellent case study to investigate the effect of topography on crater formation, crater morphology and ejecta distribution. Three-dimensional (3D) numerical simulations are required to study such complex impact scenarios.

In this study, we present a suite of numerical models of crater formation on targets with topography and relate the results to the NPCC-6 impact event on the slope of the NPCC-21 crater.

2. Model setup

We used the three-dimensional, multi-material and multi-rheology hydrocode iSALE-3D [8,9] to model the NPCC-6 impact event. The pre-landslide slope of the NPCC-21 crater rim was estimated to be 35°. The gravity was set to g=0.05 m/s^2 and the impact velocity was assumed to be 3.8 km/s, as expected on Lutetia. We used ANEOS tables [10] for dunite to compute the thermodynamic state of the material. Since the target rheology is not well known, we used different strength and material models. Thus, the simulations might result in better constraints for the surface material behavior of Lutetia.

3. Results

Our simulations suggest an impactor size of roughly 1 km required to form the NPCC-6 crater when assuming an impact angle of 30° and a projectile trajectory as illustrated by the yellow arrow in Figure 1. We found two different scenarios that match the observation quite well.

3.1 Scenario I: damaged target

Since NPCC-6 was formed at the rim of another crater, i.e. in an area where the target material is most likely damaged, we first used a simple Drucker-Prager yield criterion with a cohesion Y_{coh}= 1 kPa and a coefficient of internal friction f=0.4.

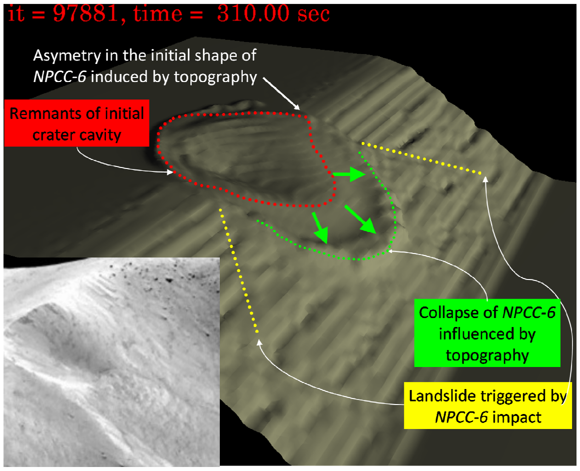

Figure 2 Scenario I (damaged target material)

The results (**Figure 2**) show that the obtained crater size and shape matches the observed crater quite well. A slight "block-slide-type" landslide event is triggered that does not agree with the observation. However, the crater collapses more pronounced downhill and, thus, might initiate a larger landslide that superimposes the smaller event. In this case the observed landslide in NPCC-21 would be caused by crater collapse of NPCC-6.

3.2 Scenario II: Acoustically fluidized target

Second, we assumed initially intact target conditions and used a strength model for rock [11], including material failure and acoustic fluidization [12].

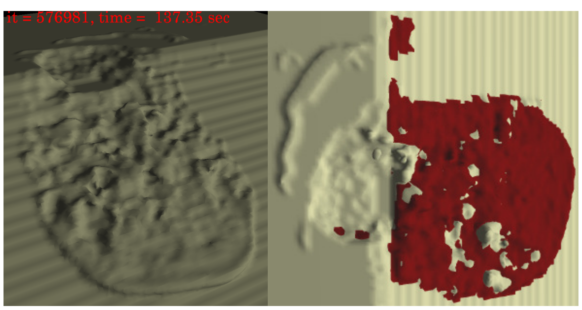

Figure 3 Scenario II (acoustically fluidized target). Left: Perspective view. Right: View from top; the landslide material is shown in red.

The resulting crater size matches the observation. In this scenario a landslide event is only triggered, if vibration of damaged material due to acoustic waves emitted by the impact is taken into account ("acoustic fluidization" [12]). This mechanism leads to (i) a different, avalanche-like style of landslide and (ii) a localization of the landslide area. The distribution of the landslide material agrees well with the observation (see Fig. 1).

4. Conclusion

Our models produce a good crater fit if initially damaged target material is assumed. Our results suggest that an additional weakening mechanism, such as acoustic fluidization, is required to limit the extension of the landslide area. Furthermore, we found that landslide events can be triggered by impacts, even on very low gravity bodies, such as Lutetia. Depending on the material rheology different types of landslides might be evoked by an impact event.

Acknowledgements

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