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Impacts into the asteroid (21) Lutetia: Comparisons of observations and models

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Abstract

We present 3-D simulations of impacts into asteroid 21 Lutetia, the subject of a fly-by by the European Space Agency's Rosetta mission to comet 67P/Churyumov-Gerasimenko. Using a 3-D shape model of the asteroid, impacts of sizes sufficient to reproduce the observed craters in Lutetia's North Polar Crater Cluster (NPCC) as observed by the OSIRIS experiment have been simulated using the smoothed particle hydrodynamics technique. The asteroid itself has been modelled both as a homogeneous body and as a body with an iron core.

1. Introduction

Images from the OSIRIS imaging system on Rosetta have been used to re-construct the global shape models of asteroid 21 Lutetia [1,2]. These models show a highly irregular shape ((126 ± 1) × (103 ± 1) × (95 ± 13) km^3). The north pole [3] is located near a depression which has been produced by multiple impacts – the North Polar Crater Cluster or NPCC [4]. Estimates from the prevalence of boulders within and in the vicinity of the NPCC [5] suggest that it must be young with an age of <300 Ma. The crater statistics suggest even younger ages.

The NPCC appears to have erased craters in a non-uniform distribution about the impact site. In addition, one of the most striking features of Lutetia is the prevalence and diversity of lineaments on the surface. Some of the observed lineament sets are >80 km long but their depths are mostly below the resolution limit of the digital terrain model (<~100 m).

Our aim is two-fold. Firstly, can the relative absence of craters surrounding the NPCC (except for the Noricum region – [6]) be explained by an impact which formed one of the elements of the NPCC? Can the ejecta pattern be modelled and can parameters be selected which lead to a reproduction of the basic features of the ejecta blanket seen on Lutetia. Secondly, can the orientations of lineaments, which are seen over most of the visible surface of Lutetia [4], be a consequence of the same impact? Does the irregular shape of the body naturally lead to the different orientations of the lineaments seen in different regions?

2. Technique

To perform the impact simulations we use a Smoothed Particle Hydrodynamics (SPH) code specially written to model geologic materials [7-9].

Using a newly implemented Drucker-Prager-like yield criterion, our method can also successfully reproduce the flow behaviour of fragmented (granular) material [10], which is important to study the late stages of crater formation. The implementation is fully 3-D taking into account the shape of the asteroid and the NPCC has been "filled-in" to simulate the pre-impact state. (The results have been tested to establish the influence of the previous shape on the solution.)

3. Results

Figure 1 shows an example result. The modelled ejecta blanket is colour-coded to give the thickness at each point on the visible hemisphere. The deposition pattern shows close similarity to inferred ejecta deposits on the surface of the asteroid. There are large deposits inside craters and on one side of the Massilia crater/depression (to the right in Figure 1) which agrees with observations outlined in [4].

Figure 2 shows an example of the velocity field arising from the impact. This case has been extracted from the model run and simulates the situation 50 s after the impact. The velocity field is not radially-symmetric about the impact site and its appearance appears to have been distorted by the irregular shape of the body. The velocity field line vectors at this time show strong similarity to the observed orientation of lineaments.

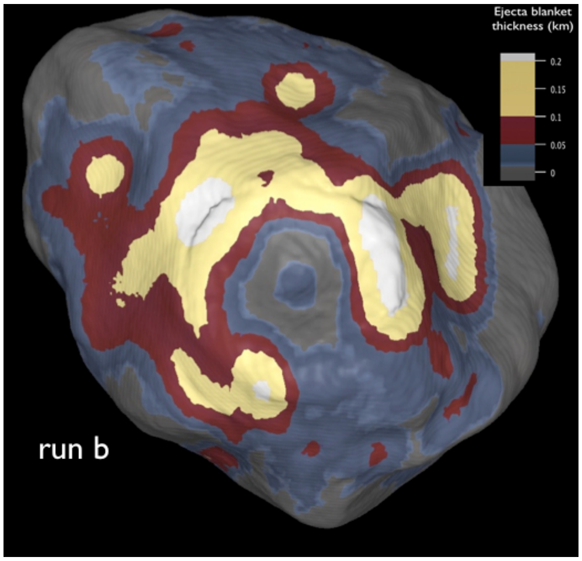

Figure 1 Example of the ejecta distribution arising from the modelled impact. Note the lack of ejecta in the lower part of the figure which is the Noricum region.

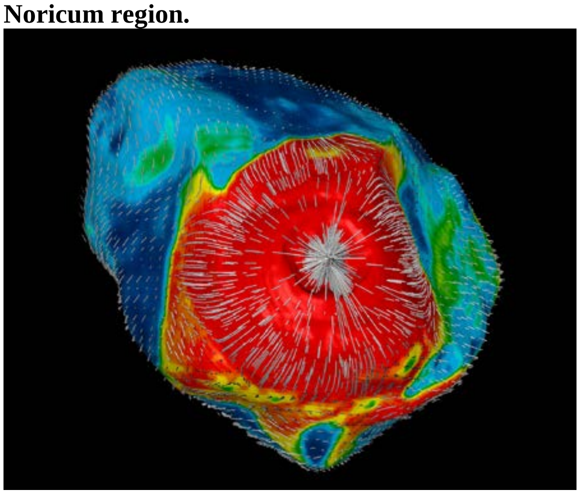

Figure 2 Model of 21 Lutetia 50 seconds after a 34 km diameter crater-forming impact. The lines indicate the local velocity. Note the non-radial nature of the velocity field. The colour code indicates the strain rate.

4. Summary and Conclusions

The ejecta distribution on 21 Lutetia resulting from the NPCC impacts is highly inhomogeneously distributed. This deposition pattern can be roughly reconstructed by using a 3D smoothed particle hydrodynamics (SPH) model with a 2.5 x 10^{20} J impact at 45° with respect to the surface normal. This geometry seems to provide a plausible explanation for the sharp boundary between the younger Baetica region and the neighbouring (older) part of the Noricum region.

Crater erasure by the shock waves generated by the impacts is more symmetric about the impact site and does not reproduce the observed spatial distribution of erased craters. It is also, on the whole, a less effective process for crater erasure.

Our model calculations show that the velocity field lines exhibit a reasonable qualitative correlation with the orientation of lineaments observed on the most of visible surface of Lutetia. This suggests that the surface velocity field and velocity shear may play a role in the generation of lineaments although there are numerous uncertainties in the mechanism.

The interior structure (core as opposed to homogeneous) of the body plays little or no role in modifying the velocity field evolution with time for reasonable choices of core size.

This abstract is a synthesis of a paper currently in revision with Icarus.

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