Accelerations and ejectas coverage in craters of a kilometer sized asteroid

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INTRODUCTION

Present on the surface of asteroids, the regolith is generally defined as a superficial blanket of loose rock material produced by impacts. Although it has always been observed on visited asteroids of tens of kilometers of diameter, the issue of the presence of regolith on a kilometer-sized asteroid is not so easy. Theoretically, the low escaped velocities (17 cm/s for Itokawa, Michikami et al., 2006) of small asteroids should not allow the formation of regolith layers. However, recent images of Itokawa have shown smooth areas of fine material and rough terrains covered with numerous boulders, evidence that regolith exists on kilometre-sized bodies (Miyamoto et al., 2006). The asteroid Itokawa also displays few craters, that could be covered or filled by loose material, according to several observations made by Barnouin-Jha et al., 2006. It is then interesting to study the erosion mechanism on a kilometre sized asteroid. This study presents 1) preliminary results on the effects of ejectas coverage on craters of a spherical asteroid of 1 km of diameter, and 2) the maximum accelerations registered in craters of the model of asteroid for a seismic shaking study (on a small asteroid, seismic energy is concentrate a long time after its injection, and a low moisture amount implies low seismic attenuations, Richardson et al., 2005). These results are given in both assumption of a strength and gravity regime since scaling laws are used. Indeed, a very small asteroid has a very low gravity field, what allows us to consider a strength controlled impact process, but a small asteroid can be a rubble pile as it is proposed for the tiny asteroid Itokawa (Cheng, 2006). This second assumption implies a gravity control of impact processes.

THE ASTEROID

The assumed model is a spherical asteroid with a stratification in densities and seismic velocities (Fig.1).

SURFACE GRAVITY:
g_a=2.5e-4 cm/s²

DIAMETER:
D = 1000 m

STRENGTH:
Y = 1e4 Pa

ESCAPE VELOCITY:
Vesc = 50 cm/s

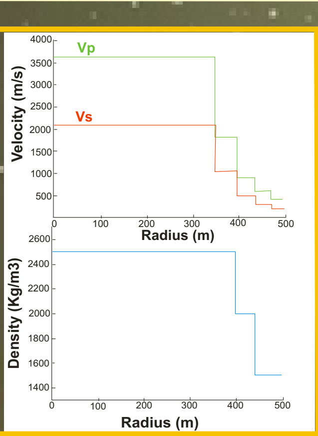

Figure 1. Seismic velocity and density profile of the asteroid

THE PROJECTILES

The model of asteroid is impacted during 30 million years by 954 projectiles ranging from 1 to 70 m (distribution law of the main belt from O'Brien et al., 2006). According to the study of Marzari et al., 1995, the diameter of the largest projectile that can impact the asteroid without breaking it is 28 m. Then, the 2 largest projectiles have not been considered in our population, leading to a largest impactor diameter of 25 m (Fig. 2).The projectiles are impacting the asteroid with a constant velocity of 5.3 km/s (Bottke et al., 1994).

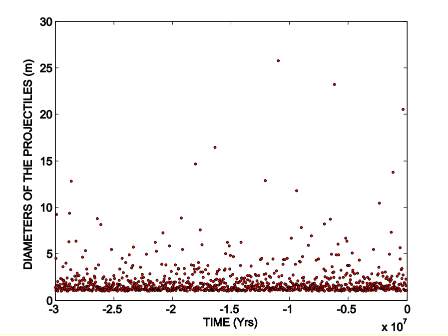

Figure 2. Diameters and impact times of the projectiles.

ACCELERATIONS HISTORY

Previous studies (Blitz et al., 2006) have made it possible to compute the maximum accelerations as a function of the epicentral distance on the model of asteroid (Fig. 5). This curve of maximum accelerations behaves linearly as a function of the kinetic momentum (m.v) of the source. The computation of the seismograms has been made with a source of 400kg impacting the asteroid at 10km/s. In the present study, each impact (characterized by the mass of the projectile and its velocity) is then considered as a seismic source producing its own acceleration curve. These curves, however, are shifted downward because seismic momentum of the impactors are inferior to the one of the 400 kg source (m.v=4e6 N.m). Knowing each falling position of the projectiles on the asteroid model, the distances between a given crater and the different impacts following its formation are computed. This last step allows us to quantify the maximum acceleration a given crater is subjected to (Fig. 6).

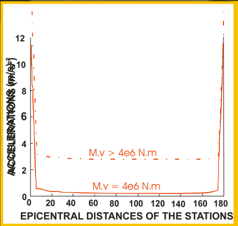

Figure 5. Accelerations as a function of the epicentral distance for a source of 400 kg impacting the asteroid at 10 km/s (solid ligne), and example for a higher seismic momentum (dot dashed ligne).

The maximum accelerations a given crater is affected by are presented in the Fig. 6 for two examples of craters. In the upper part of the Fig. 6, are plotted the maximum accelerations produced by the impacts following the formation of the first crater. The first acceleration registered occurs at -29.9 million years, the last, at t=0. Accelerations are ranging from 9.6e3 m/s² to ~ 0.1 m/s². They depend on the size of the impactor and its distance to the considered crater. The lower part of the Fig. 6 displays the maximum accelerations applied to the 476th craters (the one produced at the mid bombardment history). In that case, the accelerations are produced by projectiles hitting the asteroid from -15 million years up to t=0 (end of the bombardment). The highest acceleration, occurring at -11 million years, affects both craters.

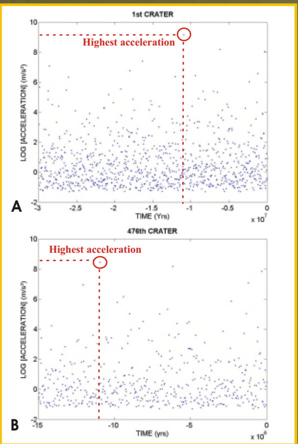

Figure 6. History of the maximum accelerations in two craters of the asteroid. A- Accelerations in the first crater dug on the asteroid (formation at t=-30 millions years). B- Accelerations in the 476th crater created on the asteroid (formation at t=-15 millions years). For largest impacts, non linear effects linked to the impactor penetration and to the finite duration of the source are not considered. Furthermore, diffraction effects are not assumed. The current hypothesis leads to overestimated accelerations.

From the two craters, it is shown that most of the impactors are leading to accelerations between 0.1 m/s² and 5 m/s². Indeed, the smallest impactors (1 m of diameter) create, whatever their distances to craters, accelerations superior to 0.1 m/s². Although this value is small in comparison to the highest acceleration, it is superior to the surface acceleration of the model of asteroid (ga=2.5e-4 cm/s²). To produce downslope movements on the craters walls, the surface acceleration of the model of asteroid has to be overcome. According to the maximum accelerations computed with the normal modes summation method, each impact leads to accelerations greater than the surface gravity. Then, we should produce downslope movements all along the bombardment, for each impact event.

EJECTAS COVERAGE

Firstly, to estimate the craters diameter Dc, we use the expression adopted by Richardson et al., 2005: Dc=30Dp, wih Dp as the projectile diameter. The total volume of ejectas per crater, such as the escaped volume of ejectas, are provided by the scaling laws method (Housen et al., 1983), for the strength and the gravity regime. From this, we have deduced a rate of 90% of ecaped ejectas for all craters in the strength regime, and a maximum rate of 30% (depending on the crater size) in the gravity regime. More ejectas are then reimpacting in the gravity regime, producing more regolith. From each crater created, we assume a homogeneous diposition of the ejectas on the surface of the asteroid. Then, each crater leads to a given regolith thickness. According to Richardson et al., 2005, the depth (d) of the crater is linked to its diameter (Dc): d=0.2 Dc. For a given crater, if the total regolith thickness produced by the following successive impacts is greater than the depth d of the crater, it is assumed that the crater is entirely filled with material. Based on this consideration, we can quantify the number of totally filled craters.

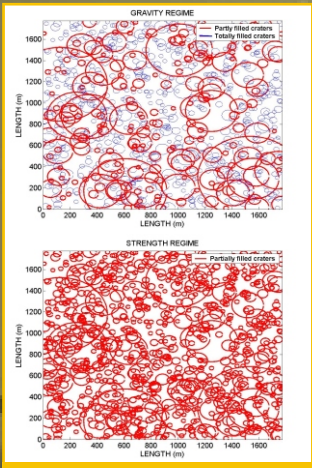

Figure 3. Representation and erosion states of the craters on the asteroid map.

Fig. 3 is displaying the localisation and state of erosion of the craters on the asteroid map (one side is the length of the perimeter of the asteroid). In the strength regime, the volumes of ejectas are low, then, the total regolith thickness provided by all impacts is 2.4 m. This prevents craters to be totally covered (the total thickness of regolith is far below the lowest depth of the smallest crater: 6 m). On the opposite, the gravity regime equations lead to numerous covered craters: 720 out of 954, since more ejectas are reimpacting. This produces a total regolith thickness of 36 m, sufficient to cover 75% of the craters.

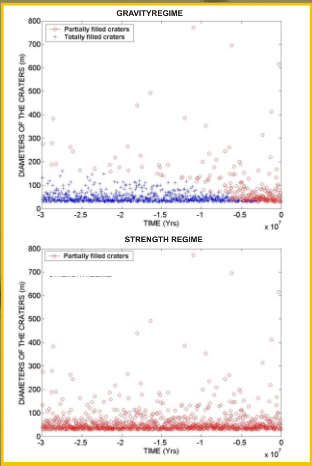

Figure 4. Sizes and erosion states of the craters as a function of their formation time.

The Fig. 4 displays the sizes and states of erosion of the craters as a function of their formation time. We observe that for being partially filled (not covered) in the gravity regime where more ejecta are reimpacting, craters have to be large enough if a lot of impacts are following them (if they are old). Then, their high depths are difficult to fill, even with numerous impacts events. In the case of small craters, they have to be recent so that few impacts occur, what prevent the total coverage of the craters. Also, we observe, like in Fig.3, that no craters are covered in the strength regime.

CONCLUSION

Even if we haven't quantified the rate of filled craters by seismic shaking yet, the present study have shown that this mechanism could have important effects on a small asteroid with a low gravity. Indeed, projectiles ranging from 1 to 25 m of diameter lead to accelerations that overcome the surface gravity of an asteroid of 1 km of diameter. This could produce downslope movements on craters walls. A further study will aim to estimate this rate by seismic shaking, keeping in mind that this mechanism should occur less efficiently on a rubble pile asteroid (this kind of structure could be acoustically dead). This study has also permitted to quantify the rate of craters covered by ejectas. Assuming hat the ejecta deposition is homogeneous on the asteroid, no covered craters has been found in the strength regime. A gravity regime hypothesis implies 75% of covered craters. We can infer that as much craters could not be observable at the surface of a gravity controlled asteroid of 1 kilometer of diameter. For a high strength asteroid, all the craters should be observable. These rates could however change if we consider a heterogeneous deposit of ejectas. This has been proposed in the study made by Geissler et al., 1996: on an ellipsoidal model of the asteroid Ida, the rotation supports preferential deposits on the leading side of the model. Then, one side of our spherical model should collect more ejectas than the other, if we assume a rotation, leading to an asymmetry in the distribution of the filled craters. With this asymmetry, totally filled craters could be produced in the strength regime. As a conclusion, we suggest that 1) craters erasure by seismic shaking is, according to this study, a realistic mechanism that can occur on an asteroid of 1 kilometer of diameter, and 2) craters erasure by ejectas coverage is more efficient for gravity controlled impact processes than for strength regime contolled impact processes.

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