POROSITY AND COLLISIONAL SEISMOLOGY OF ASTEROID INTERIORS.

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Introduction: The key to understanding the collisional history of the inner solar system lies in constraining the evolution and origin of small body interiors. Small crater erasure through impact-induced seismic shaking is a well-studied surface modification phenomenon on several main belt asteroids [1, 2]. Seismic degradation by impact is especially significant on bodies with small volume and low gravity [3]. Measurement of crater erasure caused by subsequent impacts can therefore provide unique seismological information about the composition and structure of asteroid interiors, as it relates to their degradation histories[4]. Here we apply numerical models of impacts to investigate these phenomena and illustrate how they can be used to constrain internal structure.

The attenuation properties of an asteroid's subsurface media, as well as local gravity and composition, all affect the magnitude and propagation of distant seismic effects [5]. Most asteroids are porous, to some degree, which significantly slows down seismic wave propagation and increases attenuation, so that is a key parameter to investigate. We use numerical impact simulations to study global seismicity for a variety of asteroid interiors with different porosities, with and without cores. We simulate the formation of large impacts capable of inducing significant seismic shaking on Lutetia, Vesta, and Psyche-like targets. We track stress wave propagation through the interior and correlate interior properties with the potential for distal seismic degradation.

Methods: We use the iSALE-2D shock physics code [6–8] to simulate impacts on three main belt asteroids: Lutetia, Vesta, and Psyche. We model dunite impactors of diameters 10 km, 37 km, and 30 km, respectively, striking vertically at typical impact speeds for the asteroid belt, which ranges from 4.3 to 5.5 km/s [9] depending on the body. For Lutetia and Vesta, these impactor diameters are scaled from their largest craters (Massilia and Rheasilvia, respectively), so they represent the energy transmitted through the target during those events [10, 11]. For each body, simulations are performed in 2D using cylindrical symmetry on a fixed cell Eulerian mesh with a resolution between 100 to 400 m. This is sufficient to resolve stress wave propagation, occurring seconds to minutes post-impact.

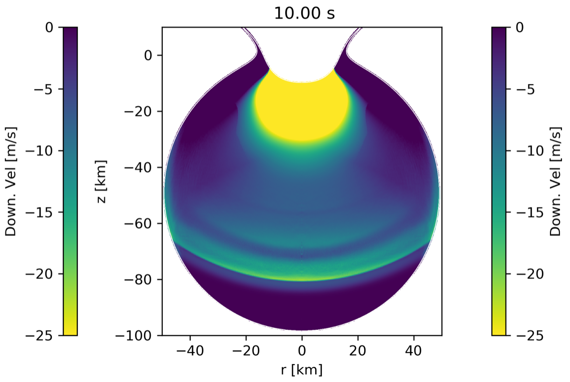
Targets are treated as spherical bodies with central gravity. Each possesses a dunite mantle and, where present, an iron core. Material properties are derived using the respective ANEOS equations of state [12, 13]. We use corresponding strength models for rock and metal following [6, 14], and the porosity model of [7]. We vary the porosity for each target following published assumptions for their interiors (Tab.1) while keeping the total mass of each body consistent.

Table 1: Two simulations were performed per asteroid, varying porosity and core mass fraction.

	Asteroid	Porosity (%)
a)	Lutetia	Non-porous, no core
b)	Lutetia	20% (mantle)
c)	Psyche	40% (core)
d)	Psyche	Non-porous core
e)	Vesta	Non-porous mantle
f)	Vesta	10% (mantle)

Results: For the Lutetia simulations, we find that the presence of a porous mantle [15] significantly affects the passage of stress waves. When Lutetia is assumed to be nonporous, the homogeneous interior allows easy pas-

a) Lutetia: Non-porous, no core



b) Lutetia: 20% porous mantle, with core

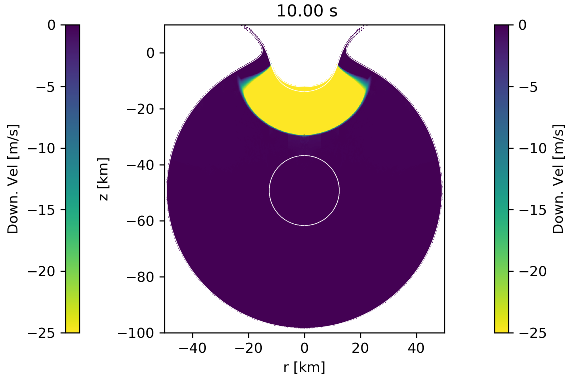
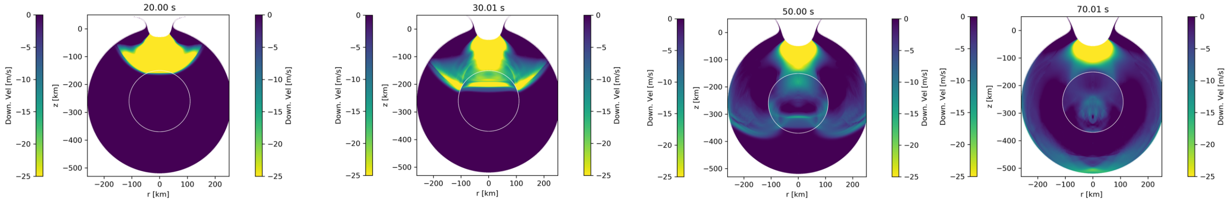


Figure 1: Comparative cross-sections representing wave passage through a Lutetia-like interior, assuming **a)** no core, non-porous mantle and **b)** 25 km diameter iron core with a 20% porous mantle, following an impact of a 10 km diameter impactor into the target surface at 4.3 km/s.

a) Vesta: Non-porous mantle



b) Vesta: 10% porous mantle

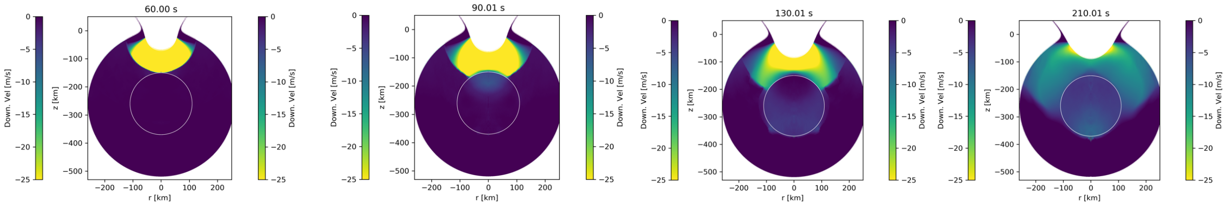


Figure 2: Wave passage (left-to-right sequence) through a Vesta-like interior assuming **a)** non-porous mantle **b)** presence of a 10% porous mantle following an impact of a 37 km diameter impactor at 5.5 km/s.

sage of the seismic waves in a short amount of time, with a clear separation between the first arrivals and the following waves (Fig.1a). Conversely, for the same model time at 10 seconds post-impact, the presence of a 20% porous mantle (Fig.1b) causes the waves to become more attenuated and pass less easily to the antipode. Moreover, wave separation is less pronounced. In this case, the presence of a small core is overshadowed by the overwhelming influence of mantle porosity.

Our results, although only for a few reference cases, confirm that porosity in planetary interiors decreases wave speed and energy through decreases in material sound speed and resulting attenuation. These effects combine to limit the extent of landform degradation. We suggest that seismic shaking on a partially porous, differentiated Lutetia would be vastly reduced, with significant degradation limited to around the impact site.

We obtain complementary results for our Vesta simulations, wherein porosity variations in the mantle (nonporous versus 10%) are studied. As seen in Fig.2a, when the mantle is nonporous, the stress wave exhibits a 'winged effect.' In this scenario, seismic waves travel faster in the mantle than the core, and the presence of the core acts like a convex lens, concentrating the seismic energy to the antipode. In the case of a porous mantle (Fig. 2b), the mantle attenuates a significant portion of the seismic energy before it reaches the core.

Similar modeling work was performed for Psyche-like targets to examine the effects of a large, 40% porous versus a smaller, nonporous core. For the former, the porosity associated with a larger core reduces energy transmitted through the interior, with negligible influence from the thin overlying mantle. Due to the higher attenuation, we observe strain localization at the equatorial region and in the vicinity of the impact point rather than the antipode.

Future Work: For actual asteroids, porosity is likely non-uniform, so in future work, we will simulate multilayered asteroids with gradational porosity. We will also implement alternative porosity models [16] for validation. We will examine in further detail how the presence and size of a core, and its porosity, affect stress wave patterns and antipodal focusing. Also, actual asteroids are not spheres, so as resolution permits, we will extend our studies to three dimensions using the SPH code SPHLATCH [17].

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