

IMPACT FORMATION MODELS OF METAL-RICH BODIES AND IMPLICATIONS FOR ASTEROID (16) PSYCHE

S. D. Raducan¹, M. Jutzi¹, T.M. Davison², G. S. Collins². ¹Space Research and Planetary Sciences, Physikalisches Institut, University of Bern, Switzerland. ² Impacts and Astromaterials Research Centre, Department of Earth Science and Engineering, Imperial College London, UK. (E-mail: sabina.raducan@unibe.ch).

Introduction: Metal-rich asteroids are widely believed to be the exposed cores of differentiated planetesimals, although the process that leads to their formation is still not well understood. One of the leading hypotheses that explains an asteroid's rich metal composition supposes that most of the primitive crust and mantle of the differentiated progenitor body was stripped off by hit-and-run collisions, leaving behind a bare core [1]. However, these collisions are not able to strip off the entirety of the mantle, without disrupting the metallic core.

Here we use numerical simulations to explore different formation scenarios for metal-rich asteroids. We also investigate the crater sizes and morphologies that may be found on such bodies today. Our results have important implications for the NASA's 'Psyche' mission at asteroid (16) Psyche [2].

Numerical Model: We use the iSALE-2D shock physics code [3, 4] to simulate high-velocity impacts into differentiated small bodies. iSALE-2D includes strength models suitable for impacts into geologic targets [5] and has been extensively validated against laboratory impact experiments [3], as well as benchmarked against other hydrocodes [6, 7]. We assume that the structure of a differentiated body has a layered configuration in which an olivine-rich mantle covers an iron core (e.g., [8]). Here we varied the mantle layer thickness between 10 and 50 km.

Formation mechanism for metal-rich asteroids: We investigated impacts in the sub-catastrophic collision regime [9, 10] as a potential formation mechanism for metal-rich small bodies. Based on our results we propose a new mechanism of efficient mantle removal on small bodies, through such impacts (after the body already experienced hit-and-run collisions). Mantle material is removed by a process of back-side spallation with minimal loss of core material. According to our numerical simulations, we find that head-on sub-catastrophic collisions can remove up to 95% of the residual mantle material from mantle-poor differentiated asteroids. The specific impact energy required to remove a given fraction of the mantle is well fit by: $Q_{crit} = a_g R^{3\mu_g}$, where a_g is a constant and μ_g is a coupling parameter to the target, in the gravity regime. Our proposed mechanism is applicable over a large range of scales, up to ≈ 1000 km. Previous studies of mantle-removing collisions have focused on much larger scales (e.g., [11, 12]).

Crater sizes and morphologies on metal-rich asteroids today: Our numerical simulations of impacts less than a few km in diameter into Psyche-analogues show that craters on metal-rich asteroids can exhibit a variety of morphologies, depending on the surface material and asteroid structure [13]. For example, if Psyche's structure is homogeneous, then craters are expected to be simple, circular depressions. For iron targets, the craters exhibit tall curled rims, characteristic of impacts into ductile materials, and large depth-to-diameter ratios compared with craters in rocky targets. On the other hand, if Psyche has a layered structure, the craters could be concentric or have flat floors. Small craters, which are more susceptible to small scale variations in the target structure, can exhibit even more exotic morphologies. The morphologies of craters on Psyche today can be used to discriminate between different formation scenarios.

Conclusions Our results suggest that metal-rich small bodies had a complicated evolutionary history and experienced more than one collision regime. We propose that sub-catastrophic, mantle-spalling impacts represent the missing link between the typical products of hit-and-run collisions and the observed metal-rich asteroids. Based on the crater morphologies on Psyche and together with our numerical simulations, we will be able to provide an insight into possible formation mechanisms for metal-rich asteroids.

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