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Unique crater morphologies on Vesta, and the context of a deep regolith and intermediate gravity

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Unique crater morphologies on Vesta, and the context of a deep regolith and intermediate gravity
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The Dawn spacecraft orbiting the minor planet Vesta has revealed details of the surface properties on a key object for the understanding of the evolution processes in an early epoch of our planetary system. In order to understand these phenomena the three dimensional structure of the surface must be deduced from identifiable processes known to be present elsewhere in the planetary system. Therefore the morphology of impact craters and their geological context (Keil 2002, Clark et al. 2002) plays an important role. They expose material at significant depth in the surface layers, they show a chronologic sequence of rearrangement of the original uppermost layer of Vesta, and their apparent mechanical properties fill the gap between topographic roughness and micro-structural photometric roughness and porosity.

Many impact craters on Vesta show significant differences to impact craters on the Moon and Mercury, where their morphology is basically dominated by a rigid surface, and to those on volatile-rich surfaces like on Mars or the icy satellites of the outer planets. The closest match with Vestan crater morphologies is that with those on Lutetia (Vincent et al. 2012). This similarity can be seen by signs of granular fluidity in land-slide phenomena. A prominent and unique property of craters on Vesta is the occurrence of features showing singular concentric central pits, which so far have been associated with liquid materials: either molten rock on Mercury or the Moon, or the liquefaction of ice on Mars, Ganymede, and Callisto (Schultz, 1988). Selected from a collection of 200 sample features in the diameter range 1 to 30 km, some prototypes of this type are presented as indicators of such a porous regolith. The prototypes include simple hopper-shaped to pan-shaped features (the basic structure), but also a subclass with approximately circular symmetric multiple-depression structure (features typically larger than 10 km), and a subclass with unusual halo shapes not observed in regular impact craters. Main criteria of establishment of a causal link between the outer halo and the inner depression are the unique coincidence of their morphologies, the consistency from an ‘evolutionary’ point of view, and a statistically significant excess with respect to the expected number of chance configurations. These criteria have been tested and confirmed. The variety of features with the basic structure is consistent with more than a single kind of process. Several active and passive modes of their generation could be identified by the observational evidence, e.g. the collapse of a porous area shaken by the seismic wave from an impact into a regolith layer with high porosity.

The required geophysical context is the presence of a sufficiently deep layer of regolith, a suitable distribution of size and shapes of its constituents, a deposit under low velocity and low pressure conditions, and a specific seismic history. These conditions are met by the giant impacts on Vesta, the ‘intermediate’ gravity (escape velocity sufficient for retention of ejecta but small for complete structural destruction by re-impactors), and the environment of craters of intermediate diameter (in the range of 10 km). Then significantly deep layers with similar properties can be created with the intact porosity of a fractal aggregate (Kaye, 1989).

Diagnostic data are the histograms of the local distribution, the determination of surface roughness on all scales. Test areas on opposite sides of Vesta with areas of 400 km2 show differences in the abundance of pit craters to normal ones by a factor of two. Locally the fraction of pit craters exceeds 50% of all, whereas elsewhere they are obviously rare. Since under-abundance is found in the low albedo hemisphere of Vesta, a correlation with composition is indicated.

The existence of the necessary conditions for the formation of a porous regolith has been tested by calculation of the trajectories of crater ejecta on the rapidly rotating object Vesta. Results show that on the trailing side of the original impact the opportunity for very slow re-impacts (less than a few meters per second) is significantly enhanced. Also the traveling times for the seismic wave and the arrival of ejecta have been compared, resulting in consistent details of the distance distribution of the related compactions.

Further evidence comes from the analysis of brightness profiles of the surface which demonstrates local smoothing. The distribution of diameter ratio of halo to central depression matches that found for the Iovian satellite Callisto, thus hinting to the granular fluidity of the regolith on Vesta. Another unique type of interacting craters on Vesta is shown, which is related to different stages of compaction of the regolith.

Concluding, it is shown that for individual features strong indications are found for a common origin of a crater and a surrounding halo by identifiable processes. A completely equivalent environment of impacts has been created by Lohse et al (2004) in laboratory, resulting in strikingly similar features. Therefore the paradigms of crater erosion and saturation have to be expanded to porous collapses. Age determinations by crater counts are affected. Although it is obvious that also some of these features were created by chance, even then the outcome in the sense of a compaction process can be studied.

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