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Erosion and contamination of the surface of Vesta

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Abstract

The data supplied by the Dawn mission revealed us that Vesta is a small world whose surface underwent a complex and violent evolution. Moreover, the ancient age of Vesta revealed by the HED (Howardite, Eucrite, Diogenite) meteorites indicates that Vesta crossed the whole history of the Solar System and suggests that its surface should have undergone an intense reprocessing due to the interplay of erosion, ejecta blanketing and contamination by exogenous material. Here we discuss how these processes could have affected the surface of Vesta during the different phases of the evolution of the Solar System.

1. Introduction

The first results of the Dawn mission revealed that Vesta underwent a complex geological and collisional history [1, 2, 3] that produced very diversified surface morphology and composition [4, 5, 6]. The confirmation of the compositional link between the HED (Howardite, Eucrite, Diogenite) meteorites and Vesta [5] implies that Vesta is one of the first planetary objects to have formed in the Solar Nebula and the only one we know of to have crossed and survived the whole evolution of the Solar System (see e.g. [7] and references therein). Moreover, the orbital position of Vesta in the asteroid belt implies that the environment it evolved in was much more violent than that of the terrestrial planets (see e.g. [7, 8] and references therein). As a consequence, the effects of the different phases of the history of the Solar System on Vesta should be evaluated in order to build a coherent framework in which to interpret the results of the Dawn mission and improve our understanding of the ancient past of our own planetary system.

2. Surface Erosion

Basing on the dating of HED meteorites, the formation of Vesta likely predates that of Jupiter (see e.g. [7] and references therein). The formation of the giant planet caused the Jovian Early Bombardment, the first and most violent bombardment event in the history of the Solar System [9]. Depending on the original orbital location of Vesta in the asteroid belt, the size-frequency distribution of the primordial asteroids and the extent of the migration of Jupiter, the intensity of the Jovian Early Bombardment on Vesta varied significantly [9, 10]. As showed in Table 1 and 2, the Jovian Early Bombardment could have stripped the original surface of Vesta of an amount of material equivalent to a shell of thickness varying between several hundreds of meters to tens of kilometres [11]. This primordial erosion of the surface of Vesta should be summed to that due to subsequent collisional evolution of Vesta (see e.g. [7, 8] and references therein) and to that due to the formation of Rheasilvia basin [12] and compared to the observed surface composition of Vesta [5] in order to constrain the evolution of the asteroid belt [13] and of the Solar System [7].

Table 1: Erosion of the surface of Vesta due to the Jovian Early Bombardment in a primordial, quiescent protoplanetary disk [11].

Migration Scenario	N_{coll}	Crustal Erosion (km)	High-Energy Impacts
0.00 AU	2574.13	0.80	0.00
0.25 AU	3322.95	0.71	0.00
0.50 AU	4608.26	3.26	0.00
1.00 AU	7184.23	14.38	0.09

3. Surface Contamination

The collisional evolution of the surface of Vesta during the Jovian Early Bombardment caused the production of a large amount of ejecta, the formation of an extensive regolith layer [14] and delivered exogenous material on the surface of the asteroid [9]. In particular, the Jovian Early Bombardment can deliver on Vesta between a few 10^{19} g to several 10^{20} g of volatile-rich material from the outer Solar System [9]. The fraction of this material that can survive the impacts

Table 2: Erosion of the surface of Vesta due to the Jovian Early Bombardment in a collisionally evolved protoplanetary disk [11].

Migration Scenario	N_{coll}	Crustal Erosion (km)	High-Energy Impacts
0.00 AU	15158.5	0.58	0.00
0.25 AU	20976.3	0.70	0.00
0.50 AU	36132.1	4.56	0.66
1.00 AU	66419.1	28.07	5.09

and remain on the surface of the asteroid is, however, uncertain and likely extremely small due to the high impact velocities associated to these events and the volatile nature of the material [9]. After the end of the Jovian Early Bombardment and of the depletion of the asteroid belt [7, 8] the rate of delivery of exogenous material on Vesta greatly diminished. It can be estimated, in fact, that all the impacts of asteroids that took place on Vesta across the last 3.5 Ga cumulatively delivered a few 10^{19} g of exogenous material, of which a few 10^{18} g would be constituted by dark, carbonaceous material. The overall amount of exogenous material that should be delivered to Vesta is equivalent to a shell with a thickness of a few meters overlapping the present surface of Vesta.

4. Summary and Conclusions

The evolution of the surface of Vesta has been complex and strongly linked to that of the asteroid belt and the Solar System, and the interplay of the different processes across the age of the asteroid make it difficult to separate the various contributions. The low gravity of Vesta likely favoured the mixing of the surface material (both indigenous and exogenous) on a planetary scale. Nevertheless, estimating and accounting for the contribution of the contrasting processes of erosion and contamination is fundamental to link the evolution of Vesta to that of its surrounding environment and thus explore the past of our own Solar System.

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