THERMAL SIMULATION OF A MAGMA OCEAN ON ASTEROID 4 VESTA.

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Introduction: Asteroid 4 Vesta is one of the most widely studied minor bodies in our Solar System. Vesta is believed to be the parent body of HED (Howardite-Eucrite-Diogenite) meteorites: its reflectance spectra closely resembles HED meteorites. Originally, it was thought that Vesta's orbital location was not propitious for providing significant flux of meteorites in Earth-crossing orbits [1]. However, the discovery of a cluster of small V-type asteroids (objects with albedos and absorption features similar to Vesta) having orbits extending from the region around Vesta to the edge of the 3:1 mean motion commensurability with Jupiter at 2.5 AU [2] has resolved the problem, since ejecta can be readily transferred to earth-crossing orbits [3]. Vesta is now recognized as third specific heavenly body, other than the Moon and Mars, for which actual rock samples are available for laboratory analysis.

HED Chronology: The radiometric ages of HED meteorites cluster around 4.4 – 4.6 Ga, according to Rb-Sr, Sm-Nd and U-Pb geochronology [e.g. 4, 5] The older ages are believed to be crystallization ages. Younger ages as low as 2.6 Ga have been reported, but are widely believed to have been reset by shock. Sm-Nd ages of cumulate eucrites indicate crystallization about 100 Myr after noncumulate eucrites [e.g. 6].

A wealth of recent work on chronology seem to point to older ages for eucrites. Thus, [7] indicate a Pb-Pb age for the eucrite Asuka 881394 of 4.566 ± 0.3 Ga. Whole rock isochrons of eucrites based on Hf-W, Al-Mg and Mn-Cr [8-10] indicate somewhat younger ages at around 4.564 Ga (or about 3.5 Myrs after CAI formation). From the perspective of thermal modeling, the old ages on noncumulate eucrites require fast accretion followed by silicate melt generation. If ^{26}Al is assumed to be the heat source, a scenario of early melting (necessary for the formation of eucrites), requires a magma ocean to form on Vesta.

Magma Ocean models of Vesta: There are two variations of proposed magma ocean model: the distinguishing characteristic is the use of equilibrium crystallization [11] or fractional crystallization models [12], respectively, to explain the petrologic trends observed in HEDs. [11] proposed a comprehensive multistage evolution of the HED parent body that satisfies many petrologic constraints except for the low volatile (Ca, Na) content of eucrites that presumably evolved from a chondritic source. [11] envisioned a early formed magma ocean with a core and molten mantle. Equilibrium crystallization in the magma ocean produced crystals of olivine, opx and spinel. The crystals remained suspended until the crystal fraction exceeded 0.8, when gravitational segregation of silicates occurred. Crystal settling formed a layer of dunite followed by a layer of diogenite. The residual liquids generated the Main Group Eucrites, whereas fractionation of evolved liquids within the crust is believed to have generated the Nuevo Laredo trend [11].

Methodology: [13] presented the first thermal model of Asteroid 4 Vesta using ^{26}Al as a heat source. In the present abstract, we refine the thermal model to include a scenario of a magma ocean. The heat transfer equation is solved by the finite element method for a spherical asteroid using ^{26}Al and ^{60}Fe as heat sources. Accretion is assumed to be incremental and a radiation boundary condition is used to approximate heat loss from the body. Thermal diffusivity and specific heat are recalculated for each rock type. For clarity in modeling, the calculation is divided into five temporal domains: Stage 1: Accretion; Stage 2: Heating of homogenous asteroid until core separation; Stage 3: Further heating of the mantle until magma ocean forms; Stage 4: Cooling of the magma ocean; Stage 5: Cooling of the core, mantle and crust. Parameterized convection is implemented using [14].

Results: Assuming a H-Chondrite composition and homogeneous distribution of ^{26}Al, initial results indicate that a magma ocean scenario on Vesta requires an accretion time of <2 Myrs. In a magma ocean scenario, the igneous crystallization ages on noncumulate eucrites can range from about 2 Myr, for the first formed melt >5 Myrs for the last residual liquid.

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Figure 1: A contour plot of Time (in Myrs. relative to CAI Formation), Distance (in kms.) from the center of Vesta and Temperature (in K). The initial composition of Vesta is assumed to be H-chondrite and the percent melting is assumed to be 80%. The plot shows temperature evolution in the near surface layers of Vesta in a magma ocean scenario.