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Vesta Thermal Models

M. Formisano (1), C. Federico (2) and A. Coradini (3)
(1) Dip. di Fisica, Università di Roma "La Sapienza", Piazzale Aldo Moro 5, I-00185 Roma, Italy,
(2) Dip. di Scienze della Terra - Università degli Studi di Perugia, 06123 Perugia, Italy,
(3) INAF - IFSI, Via Fosso del Cavaliere 100 -00133 Roma, Italy
email address: michelangelo.formisano@iasf-roma.inaf.it

Abstract

Vesta thermal evolution and structural models based on radiogenic heating are compared. In all the models, differing for the delay in injection (Δt_d) of ^{26}Al (the primary heat source) by the nebula in which Vesta was formed, we observe the differentiation of the asteroids leading to the formation of a metallic core (mainly iron) and a silicatic crust of which we study the chemical and physical evolution. We also analyze the contribution of long-lived radionuclides, in particular ^{40}K, ^{232}Th, ^{235}U and ^{238}U.

1. Introduction

Vesta, considered the parent of the HED (Howardite−Eucrite−Diogenite) [1] meteorites, is the second most massive asteroid of the Main Belt. It has a differentiated structure consisting of a core (mostly iron), an overlying rocky olivine mantle and a basaltic crust. The process of differentiation occurs through the decay of radioactive elements such as ^{26}Al (the primary heat source) and ^{60}Fe. The long-lived radionuclides contribution does not change the overall thermal history but it is important only to delay the cooling of the asteroid. The importance of studying the thermal evolution of Vesta is linked to understanding of processes of core and crust formation in planetary bodies so Vesta can be considered a good model for the primordial stages of the terrestrial planets.

2. Thermal Model

The thermal models adopted are considered "instantaneous" for the neglecting of the accretion time of Vesta and differ for the delay in injection of ^{26}Al by the nebula in which Vesta was formed. We fix the radius equal to 270 Km and the total mass to 2.75×10^{20} Kg. The initial temperature (that is also the surface temperature) is fixed to 200 K. When melting temperature of Fe-FeS is reached the differentiation (due to permeable flow [3]) and subsequent core formation occur. Considering Vesta initially composed partly silicatic (0.77%) and partly metallic (0.23%), we solve numerically (using a finite-difference method in 1D radial direction with donor-cell scheme) the following set of differential equations [5]:

$$(\rho c)_m \frac{\partial T}{\partial t} + (\rho c)_f \vec{v} \cdot \vec{\nabla} T = \vec{\nabla} \cdot (K_m \vec{\nabla} T) + H \quad (1)$$

$$\frac{\partial C}{\partial t} + \vec{v} \cdot \nabla T = \nabla \cdot (D_m \nabla C). \quad (2)$$

In eq.1 it is assumed the local thermal equilibrium (so $T_s = T_f = T$ in which s stands for solid and f for fluid), taking averages over an elemental volume. The term H represent the heat production by radionuclides decay per unit volume. The terms $(\rho c)_m = (1 - \Phi)(\rho c)_s + \Phi(\rho c)_f$ and $K_m = (1-\Phi)K_s + \Phi K_f$ represent the overall heat capacity and thermal conductivity respectively. Following Ghosh and McSween [2] we use "windows" of temperature in which the entire latent heat for metal and silicate melting is assumed to be expended [2]. In eq.2 C represents the concentration of silicate component and $D_m = 10^{-6} m^2 s^{-1}$ is the diffusion coefficient. The heat provided by the ^{26}Al is expressed as [6]:

$$H_{Al} = \rho C [^{26}Al]_0 H^* e^{-\lambda t}, \quad (3)$$

in which ρ is the density of the silicate component, λ is the decay constant and H^* is the specific power production. The heat provided by the decay of ^{60}Fe and long-lived radionuclides is treated similarly.

3. Summary and Conclusions

Four models are studied: the Model 1, 2, 3 and 4 are characterized by a time delay $\Delta t_d = 0$, $\Delta t_d = 0.5$

$T_{1/2}^{Al}$, $\Delta t_d = 1\ T_{1/2}^{Al}$ and $\Delta t_d = 1.50\ T_{1/2}^{Al}$, respectively. Obviously, the smaller the delay the greater the intensity of radioactive sources. The mean innovation of this model respect Ghosh and McSween (1998) [2] is the movement of the silicate component during the differentiation from the forming core to the mantle region: this fact is important because the silicate component drags the ^{26}Al that is the main energy source so the temperature increases with the radius. The decrease in temperature of the outer part of the body is due to the irradiation of the energy. Fig.1 shows the temperature profile for a fixed time from Vesta accretion for the four models considered, Fig.2 shows the profile of the inner composition for a selected model. The thickness of the crust is determined by the intersection (that moves in the time) between the temperature profile with the isothermal of the melting temperature of Fe-FeS and it is another main difference with Ghosh and McSween (1998) because they fixed this point in their models. By the Fig.2 it is possible to estimate the size of the core by the intersections between the profile of the concentration of ^{26}Al and ^{60}Fe. Currently we are testing the possibility to introduce other radioactive heat sources (i.e. ^{25}Mn) and to consider impact with other bodies as source of energy. Furthermore we are developing models in which the accretion is not instantaneous and so it contributes to the thermal history.

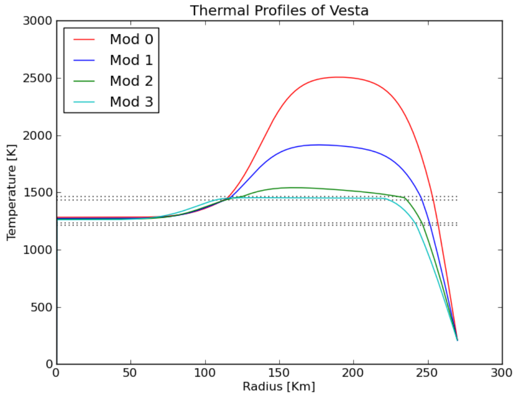

Figure 1: Thermal profiles of Vesta for the different models analyzed at t = 5 Myr. The dotted lines represent the temperature "windows" in which the entire latent heat for metal and silicate melting is assumed to be expended.

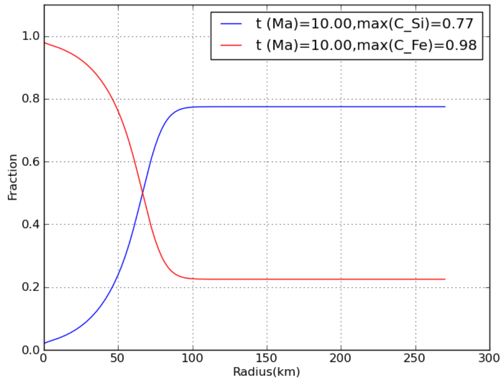

Figure 2: Example of inner composition profile (for Mod 3 at t = 10 Myr).The intersection between the concentration of the metallic component (in red) with the silicatic one (in blue) gives an estimate of the core radius.

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