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Primordial history of Vesta: time scale of accretion and physical properties of the proto-core

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Abstract

The importance of studying Vesta is linked to the presence of a differentiated internal structure, inferred by the spectral connection with HED meteorites (Keil et al.2002, Scott 2007, De Sanctis et al.2012). We simulate several scenarios of thermal and structural evolution of Vesta by using the thermal code we developed. By varying the delay-parameter Δt_d in the injection of ^{26}Al in Vesta and the initial concentration of metallic and silicate components of the asteroid, we explore the primordial thermal history of Vesta and in particular we search for information about the physical properties of the proto-core.

1. Introduction

Recent results (Schiller et al.2011) reveal a faster cooling rate of the interior of Vesta than previously thought and, if confirmed, the thermal history could radically diverge from the generally accepted picture (Ghosh & McSween 1998). We study the primordial history of Vesta by developing several scenarios in which the thermal (and consequently the structural) evolution is controlled by the decay of the short-lived radionuclides (in particular ^{26}Al) in which the delay-parameter Δt_d plays a key-role in determining the strength of the radiogenic sources.

2. Numerical Procedure: Geophysical model of Vesta

We consider primordial Vesta as a homogeneous sphere with radius of to 270 km and initial temperature (that is also the surface temperature) of 200 K. The initial composition is 21% metal, 69% silicate, with a global porosity of 10%. Our code simultaneously solve, in finite-difference method with Lax scheme, the following equations:

$$(\rho c_p)_T \frac{\partial T}{\partial t} = \frac{1}{r^2}\frac{\partial}{\partial r}\left[K(r)\, r^2 \frac{\partial T}{\partial r}\right] + \rho_T H(r,t)$$
$$\frac{\partial C}{\partial t} + v\frac{\partial C}{\partial r} = 0. \quad (1)$$

The first equation is the heat equation, in spherical coordinates, with the radiogenic heat term. The second one is the advection equation which controls the percolation rate of the metallic (iron) component. When the melting temperature of Fe-FeS is reached (see Fig.1), the percolation of iron into the silicate matrix and the formation of the proto-core take place. Since our model does not take into account heat removal mechanisms other than conduction and irradiation at the surface, our results supply a reliable picture of the thermal history of Vesta up until the onset of the differentiation (see Fig.2).

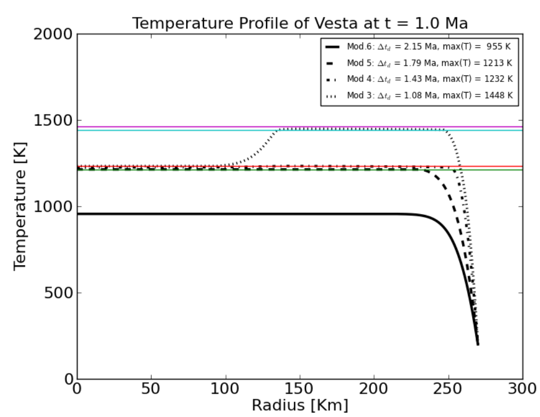

Figure 1: Temperature profile of Vesta at t = 1Ma for the several scenarios characterized by different time-delay parameters.

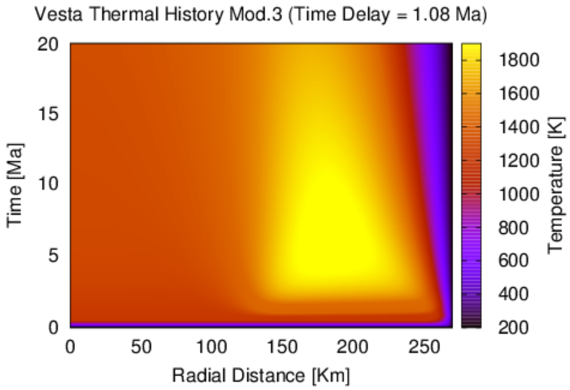

Figure 2: Thermal and Structural Map of Vesta for t < 20 Ma and $\Delta t_d = 1.08$ Ma.

3. Summary and Conclusions

When compared to the data provided by HED meteorites, our results suggest short accretion and differentiation times of Vesta respect to the condensation of CAIs. The scenarios characterized by $\Delta t_d > 2$ Ma show temperature not reaching the melting temperature of silicate and so they are incompatible with the basaltic magmatism suggested by HEDs (Keil et al. 2002, Bizzarro 2005). In the scenarios with 1.5 Ma $< \Delta t_d < 2$ Ma, silicate melting occurs at about t = 6 Ma: this is incompatible with the crystallization ages of the oldest HEDs (Schiller et al 2001, Bizzarro 2005). Finally, values of $\Delta t_d < 1$ Ma are the most compatible with the geologic history of Vesta as suggested by HEDs. In Tab.1 we report the physical properties of the core, for the several scenarios, after 20 Ma. We observe that the maximum radius of the proto-core is reached in the scenario with instantaneous accretion: the formation time of the core is about 0.159 Ma. The scenarios characterized by a late accretion ($1 < \Delta t_d < 2.5{t_{1/2}}^{26}Al$) led to a core size in the range 137-161 km with a formation time in the range 0.530-1.654 Ma. In the scenario with a $\Delta t_d = 3{t_{1/2}}^{26}Al$, there is no metal melting and Vesta remains undifferentiated.

	Core Size $[km]$	**Core Time Formation** $[Ma]$	**Density** $[Kg\, m^{-3}]$
	Scenario 0: $\Delta t_d = 0{t_{1/2}}^{26}Al$		
$\phi = 0.10$, $X = 0.69$, $Y = 0.21$	196	0.159	4041
	Scenario 1: $\Delta t_d = 0.5{t_{1/2}}^{26}Al$		
$\phi = 0.10$, $X = 0.69$, $Y = 0.21$	171	0.235	4390
	Scenario 2: $\Delta t_d = 1{t_{1/2}}^{26}Al$		
$\phi = 0.10$, $X = 0.69$, $Y = 0.21$	167	0.345	4366
	Scenario 3: $\Delta t_d = 1.5{t_{1/2}}^{26}Al$		
$\phi = 0.10$, $X = 0.69$, $Y = 0.21$	161	0.530	4388
	Scenario 4: $\Delta t_d = 2{t_{1/2}}^{26}Al$		
$\phi = 0.10$, $X = 0.69$, $Y = 0.21$	156	0.860	3885
	Scenario 5: $\Delta t_d = 2.5{t_{1/2}}^{26}Al$		
$\phi = 0.10$, $X = 0.69$, $Y = 0.21$	137	1.654	3885
	Scenario 6: $\Delta t_d = 3{t_{1/2}}^{26}Al$		
$\phi = 0.10$, $X = 0.69$, $Y = 0.21$	NO	NO	NO

Table 1: Summary of scenarios developed with constraints on size, time formation and density of the core, after 20 Ma. ϕ = porosity, X = silicate, Y = metal. NO stands for non formation of the core.

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