EPSC Abstracts
Vol. 8, EPSC2013-995, 2013
European Planetary Science Congress 2013

The heating history of Vesta and the onset of differentiation

M. Formisano (1), C. Federico (1,2), D. Turrini (1), F. Capaccioni (1), M.C. De Sanctis (1), C. Pauselli (2)
(1) INAF-IAPS, Via Fosso del Cavaliere 100, I-00133 Roma (Italy); (2) Department of Earth Science, University of Perugia, I-06123, Perugia (Italy)

Abstract

We studied the link between the evolution of the internal structure of Vesta and thermal heating due to ^{26}Al and ^{60}Fe and long-lived radionuclides, taking into account the chemical differentiation of the body and the affinity of ^{26}Al with silicates. We explored several thermal and structural scenarios differing in the available strength of energy due to the radiogenic heating and in the post-sintering macroporosity. By comparing them with the data supplied by the HEDs and the Dawn NASA mission (Russell et al. 2012), we used our results to constrain the accretion and differentiation time as well as the physical properties of the core. This work provides a theoretical support to data analysis for the Dawn mission, which addresses the investigation of the Vesta's internal structure as well as the composition of the crust and of the underlying mantle in the region of giant impact basins.

1. Introduction

Vesta is the most geologically diverse of the large asteroids, showing a surface geology as differentiated as the one of the Moon and Mars as revealed by resolved images taken by the the Hubble Space Telescope and recently confirmed by the spectroscopic measurements of the Dawn mission (De Sanctis et al. (2012)). In order to study the geophysical and thermal history of this asteroid, we developed a 1D heat conduction model with radiogenic heat source and with black-body radiation at the surface. We assumed as a critical parameter the delay time Δt_d, which incorporates both the delay in the injection of ^{26}Al in the Solar Nebula and the temporal interval covered by the accretion time of Vesta. The scenarios we developed are labeled as N0 ($\Delta t_d \simeq 0$, i.e., instantaneous accretion), N1 ($\Delta t_d \simeq$0.3 Ma), N2 ($\Delta t_d \simeq$0.7 Ma), N3 ($\Delta t_d \simeq$1.4 Ma).The delay time Δt_d is important because it determines the content of radioactive material at the onset of the thermal evolution of Vesta. The longer the delay time, the weaker is the available source. We also developed sub-scenarios characterized by different post-sintering porosity in order to improve the treatment of the internal structure of the rocky asteroid, in particular the formation and the evolution of the core, by studying its physical and chemical properties, and to depict the primordial history of 4 Vesta (and in general of all rocky asteroid partially or completely differentiated), constraining the accretion and differentiation times and the size of the crust.

2. Physical Description of the Model

We assumed Vesta as a spherical body of fixed radius equal to 270 km and initially composed of a homogenous mixture of two components, similar to those of the H and L classes of the ordinary chondrites, which contain significant amounts of metals (McSween (1990)) even if the inferred composition for Vesta is slightly different, as it appears to be strongly depleted in sodium and potassium (Consolmagno & Drake (1977)). The post-sintering porosity ranges from 1 to 5 vol.%. The initial temperature (T0) of the body (that is also the local temperature of the Solar Nebula) is fixed to 200 K (Lewis (1974)). We impose a radiation boundary condition at the surface and a Neumann boundary condition (heat flux equal to zero). The percolation of metals through silicate matrix is controlled by the advection equation, in which the velocity is given by Darcy's law. Following Merk et al. (2002), the specific heat is modified through the Stefan coefficient to take into account in a simple way the latent heat during phase transition.

3. Figures

We reported an example of thermal history map, for porosity = 1% by volume, of N0-N3 scenarios.

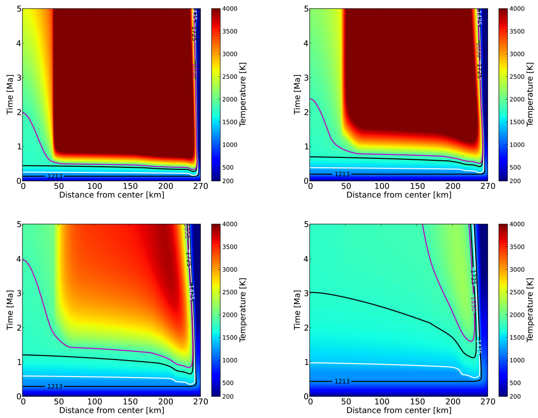

Figure 1: Thermal history maps, for porosity = 1% by volume, of N0 (a), N1 (b), N2 (c), N3 (d). Black isoline (1213 K) identifies the onset of metal melting; white (1425 K), black (1725 K) and magenta (1850 K) isolines identify the onset, the 50 vol.% and the complete melting of silicates, respectively.

4. Summary and Conclusions

In all those scenarios where Vesta completes its formation in less than 1 Ma from the injection of ^{26}Al, the degree of silicate melting reaches 100 vol% throughout the whole asteroid. If Vesta completed its formation between 1 and 1.4 Ma after ^{26}Al injection, the degree of silicate melting exceeds 50 vol.% over the whole asteroid but reaches 100 vol.% only in the hottest, outermost part of the mantle in all scenarios where the porosity is lower than 5 vol.%. If the formation of Vesta occurred later than 1.5 Ma after the injection of ^{26}Al, the degree of silicate melting is always lower than 50 vol.% and is limited only to a small region of the asteroid. The N0-N3 scenarios are compatible with the results of Greenwood et al. (2005) which link the formation of eucrite and diogenite to large scale (>50 vol.%) melting of the silicates. This would imply Vesta formed no later than 1 Ma after injection of ^{26}Al. The radiation at the surface dominates the evolution of the crust which ranges in thickness from 8 to about 30 km after 5 Ma: a layer about 3-20 km thick is composed of primitive unmelted chondritic material while a layer of about 5-10 km is eucritic, which can already form between 3 and 5 Ma, in agreement with the dating of the oldest eucrites described by Bizzarro et al. (2005).

Acknowledgements

We wish to thank Guy J. Consolmagno, Sin-Iti Sirono and Gal Sarid for their helpful suggestions and comments and Romolo Politi for his numerical analysis assistance. We also wish to thank Harry Y. McSween, Sandeep Sahijpal, Gregor Golabek, Paul Tackley. This work is supported by ASI grant.

References

[1] Bizzarro, M., Baker, J.A., Haack, H., and Lundagaard K.L.: Rapid Timescales for Accretion and Melting of Differentiated Planetesimals Inferred from 26Al -26Mg Chronometry. The Astrophysical Journal 632:L41-L44, 2005.

[2] Consolmagno, G.J., and Drake M.J.: Composition and evolution of the eucrite parent body - Evidence from rare earth elements. Geochimica et Cosmochimica Acta 41:1271-1282, 1977.

[3] De Sanctis M.C., and 22 collegues: Spectoscopic Characterization of Mineralogy and Its Diversity Across Vesta. Science 336:697, 2012.

[4] Greenwood, R.C., Franchi, I.A., Jambon, A., and Buchanan P.C.: Widespread Magma Oceans On Asteroidal Bodies In The Early Solar System. Nature 435:916-918, 2005.

[5] Lewis, J.S.: The temperature gradient in the solar nebula. Science 186:440-443, 1974.

[6] McSween, H.Y.: Asteroids II. Ed. by Binzel, R.P., Gehrels T. and Matthews, M.S., Tucson, Univ. Arizona Press 1989. Geochimica et Cosmochimica Acta 54:1528-1529, 1990.

[7] Merk, R., Breuer, D., and Spohn T.: Numerical Modeling of ^{26}Al Induced Radioactive Melting of Asteroids Considering Accretion. Icarus 159:183-191, 2002.

[8] Russell, C., and 27 colleagues: Dawn at Vesta: Testing the Protoplanetary Paradigm. Science 336:684-686, 2012.