VESTA THERMAL EVOLUTION REVISITED. C. Federico[1], A. Frigeri[1] C. Pauselli[1] and A. Coradini[2], [1]Dipartimento di Scienze della Terra: Sezione di Geologia Strutturale e Geofisica, Università degli Studi di Perugia Piazza dell'Università 06124 PERUGIA, [2] IFSI INAF Via Fosso del Cavaliere 100 00133 ROMA

Introduction: Vesta - based on the Hubble observations and the relationship with HED (Howardite-Eucrite-Diogenite) meteorites - underwent early in its history to a substantial differentiation. From spectroscopic point of view it appears that some of the terrains of Vesta have a typical pyroxene signature. In particular, it is the presence of the 0.9 and 1.9 micrometer absorption bands for pyroxene in the spectra of Vesta that match spectra of the HED meteorites. After the crust formation, Vesta underwent to intense and extended resurfacing, as can be inferred by the presence of a great crater on the South Pole. Vesta is the only known intact asteroid that has been resurfaced in this way. However, the presence of iron meteorites and achondritic meteorite classes, without identified parent bodies, indicates that there once were other differentiated planetesimals with igneous histories, which have since been broken by impacts. Therefore Vesta can be used as a reasonable model for the infantile stages of the terrestrial planets.

Vesta's surface is a mixture of three rock types: diogenites, basaltic eucrites, and cumulate eucrites. Diogenites are cumulates that formed at depth, made mostly of magnesium-rich, calcium-poor orthopyroxene. Eucrites have basaltic compositions with iron-rich pyroxene and sodium-poor plagioclase and may have formed from surface or near-surface lavas or as cumulates. Together with howardites, which are breccias of fragments of eucrites and diogenites, these rock types are known collectively as the howardite-eucrite-diogenite meteorite class or HEDs. It is also known that some basaltic eucrites were later metamorphosed by heat, showing that once Vesta differentiated, it undergo to a further impact history. In fact Hubble Space Telescope images show a 460 km diameter impact basin at the south pole of Vesta.

Vesta thermal history based on Geochemical models. The link between the HEDs and the thermal history is related to the need to form a large body of "hot" material (magma ocean like on the Moon?) to explain the formation of Diogenite. Experimental petrology[1] demonstrated that the eucrites (the relatively unaltered and unmixed basaltic achondrites) were the product of approximately a 10% melt.. Studies of siderophile element partitioning suggested that this melt was the residue of an asteroidal-scale magma ocean [1]. During the cooling of this ocean equilibrium crystallization is assumed. According to [2] a possible thermal history can be traced, as follows: a) melting due to radioactive decay of ^{26}Al, leading to separation of the metal core. b) Progressive crystallization of a convecting molten mantle. Convection stopped when large part of the material had crystallized. c) Residual liquid is pushed at the surface and crystal accumulate at depht. d) The residual localized liquid can give rise to evolved basalts. The deeper layers of the crust crystallize to form plutonic rocks, while older basalts are metamorphosed due to the pressure of newer surface layers. e) Slow cooling of the interior. f) Finally, impacts can penetrate the crust exposing underneath material and allowing the spectroscopic investigation of subsurface units.

Heat source strength This interesting scenario seems to be contradicted by Kunihiro et al (2004) [3], who, measuring ^{26}Mg excesses correlated with Al/Mg ratios in five chondrules from the primitive CO3.0 chondrite Yamato 81020, yield a mean initial ^{26}Al/^{27}Al ratio of only $(3.8 \pm 0.7) \times 10^{-6}$, about half that of ordinary chondrite (OC) chondrules. Even if asteroids formed immediately after chondrule formation, this ratio and the mean Al content of CO chondrites is only capable of raising the temperature of a well-insulated CO asteroid to 940 K, which is more than 560 K too low to produce differentiation. If so, it is very difficult to accept the previously described scenario. The same ratio combined with the higher Al content of CV chondrites results in a CV asteroid temperature of 1100 K. Kunihiro et al (2004) [3] calculate that the mean initial ^{26}Al/^{27}Al ratio of about 7.4×10^{-6} found in LL chondrules is only able to produce small amounts of melting, too little to produce differentiation. Therefore the authors suggest that they results generate serious doubt on the viability of ^{26}Al as the heat source responsible for asteroid differentiation.

However, Kleine et al. 2004 [4], using new high-precision W isotope data on iron meteorites, provide important constraints on the timing of silicate–metal segregation in planetesimals. They [4] have shown that iron meteorites are as old and older than refractory calcium–aluminum rich inclusions (CAI), which are widely thought to be the oldest solar system objects. The authors suggest [4] that core formation in parent bodies of magmatic iron meteorites occurred ≤ 1.5 Ma after the formation age of CAI [5] This extremely early metal–silicate differentiation is coeval with the first chondrules [5]. The authors conclude that early planetary accretion and differentiation was sufficiently fast for ^{26}Al-decay to be an important heat source. Bizzarro et al. [6] suggest that primitive or undifferentiated meteorites (chondrites) date back to the origin of the Solar System, and thus preserve a record of the physical and chemical processes that occurred during the earliest evolution of the accretion disk surrounding the young Sun. Bizzarro et al.[6] report the presence of excess ^{26}Mg resulting from *in situ* decay of the short-lived ^{26}Al nuclide in CAIs and chondrules from the Allende meteorite. Six CAIs define an isochron corresponding to an initial ^{26}Al/^{27}Al ratio of (5.25 ±0.10) ×10^{-5}, and individual model ages with uncertainties as low as ±30000 years, suggesting that these objects possibly formed over a period as short as 50000 years. In contrast, the chondrules record a range of initial ^{26}Al/^{27}Al ratios from 5.66 to 1.36 × 10^{-5}, indicating that Allende chondrule formation began contemporaneously with the formation of CAIs, and continued for at least 1.4 Ma.Given these incertituteds we have decided to trace thermal history of Vesta considering two “extreme” scenarios: the first assuming a mean conservative value of the ratio ^{26}Al/^{27}Al, equal to 3.8 10^{-6} [3]. The second one assuming a higher value of the same ratio, i.e. ^{26}Al/^{27}Al ratio of 5.25 10^{-5}, as suggested by [6].

Our Model We solve the 3D heat transfer equation using the Finite Element Method (FEM) for a spherical object whose mean radius is equal to the one obtained for Vesta (R=260 km). We use the C++library called DOLFIN [7] whose characteristics features are well suited to solve PDE and in particular the diffusion equation. In 3D adaptive tetrahedral mesh refinement is used. We have tested our 3D spherical numerical solution of the heat diffusion equation comparing our results with those analytically obtained for the same spherical asteroids by [3]. The obtained results are identical in values and in time behavior. It is to be noted that increasing the radius of the object (from R=10 km to R=60 km) the time evolution of the temperature calculated at the center of the object, r=0 and at a distance equal to r=R/2 becomes more and more equal. In the case of Vesta, all other parameters being equal, varying the initial concentration of ^{26}Al we obtain different results (Figure 1). In fact when ^{26}Al/^{27}Al is equal to 3.8 10^{-6} no melting temperature is reached, when ^{26}Al/^{27}Al is equal to 5.25 10^{-5} unreasonably high temperature are reached, while when ^{26}Al/^{27}Al is equal to 1.25 10^{-5} reasonably temperature for melting is reached (1500 K). Noting that the time interval to go from 3.8 10^{-6} to 1.25 10^{-5} is equal to 1.2 Ma, we may suppose that the starting time for accretion of Vesta is estimated as 1 Ma after CAI formation in good agreement with [8]

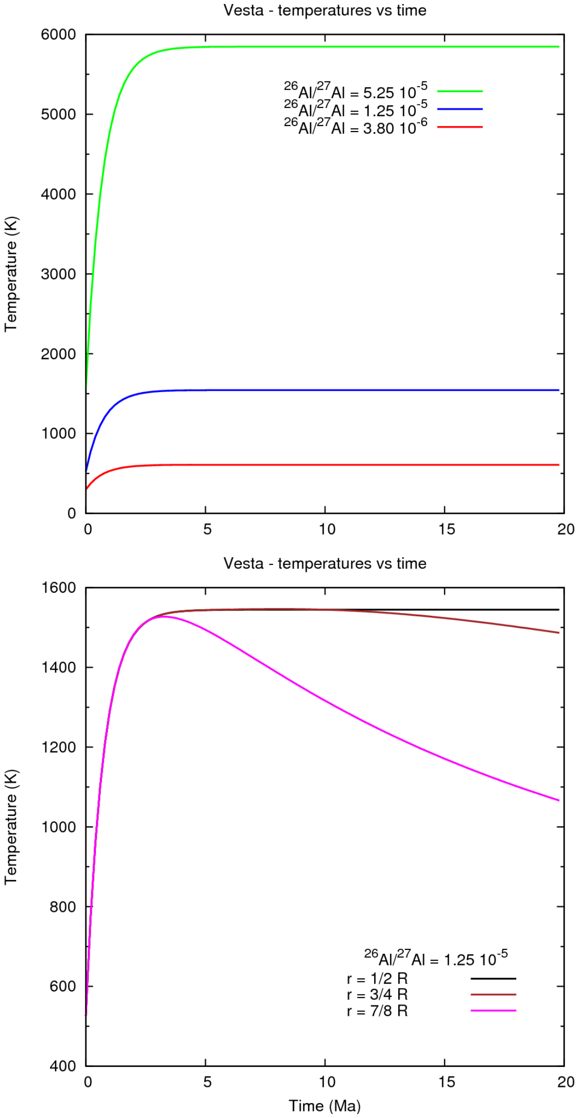

Figure 1 Thermal history at the center of Vesta for different initial ^{26}Al/^{27}Al concentration (top). Thermal history at different points inside Vesta for a fixed ^{26}Al/^{27}Al concentration (bottom).

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