AN EXTENDED THERMAL HISTORY (100 Ma LONG) FOR ASTEROID 4 VESTA BASED ON RADIONUCLIDE AND COLLISIONAL HEATING. Amitabha Ghosh and Harry Y. McSween Jr., Dept of Geological Sciences, University of Tennessee, Knoxville, TN 37996.

Thermal modeling has so far been done on small asteroids with radii of 100 km or less. In this study, we attempt to model a larger body, asteroid 4 Vesta, which has a radius of 275 km. Previous models have only attempted to explain thermal metamorphism and aqueous alteration, not igneous activity and core formation. In tracing the thermal evolution of a body such as Vesta, it becomes important to account for the latent heat of fusion and the increased specific heat capacity of melts, as well as to consider the possible effects of collisional heating and the redistribution of radioactive nuclides (^{26}Al and ^{60}Fe) during differentiation.

Geochronology of HED meteorites

The ages of HED meteorites cluster around 4.4 - 4.6 Ga according to Rb-Sr, Sm- Nd and U-Pb geochronology [1] . Significantly, Sm-Nd ages for cumulate eucrites indicate relatively young ages of 4.46 - 4.41 Ga [2, 3, 4] compared to the 4.52 - 4.56 Ga ages obtained for noncumulate eucrites [5, 6], suggesting a maximum spread of perhaps 100 Ma. Also, diogenites have Rb-Sr ages of less than 4.5 Ga [7,8]. Workers who interpret the ages of cumulate eucrites and diogenites as crystallization ages have had problems in reconciling this extended interval with the hypothesis of ^{26}Al as a heat source, because this radionuclide cannot sustain its potency beyond a few million years after the eruption of non-cumulate eucrites [e.g. 9]. (It is also possible that younger ages represent blocking temperatures rather than crystallization ages; however, an extended thermal history of 100 Ma would still be necessary, though maximum temperatures could be subsolidus.)

Basic Equation and Methodology

Vesta is assumed to grow from the accretion of 10 km planetesimals according to a formulation by Wetherill [10]. The energy balance is given by the heat transfer equation, and heat loss from the surface of the body is governed by a radiation boundary condition. Thermal diffusivity and specific heat capacities are recalculated for each temperature. The body is heated by the decay of ^{26}Al and ^{60}Fe. ^{60}Fe is included in the calculations to assess whether it can cause any significant heating in the mantle of Vesta when iron is sequestered to form the core. The collisional heat generated during accretion is approximated according to [11]. The initial composition of the planetesimal is assumed to be generic H-chondrite, with average composition given by [12]. The computation was implemented on a Cray Y-MP supercomputer.

Chronologically, the thermal model can be divided into four stages.: Stage-1: Accretion of Vesta from 10 km bodies; Stage-2: Radiogenic heating of a homogenous asteroid until core separation (beginning at around 980°C, based on chondrite melting experiments [13]); Stage-3: Further heating of the mantle until silicate partial melting and crust formation (beginning at 1190°C, based on eucrite melting experiments [14]); Stage-4: Further heating and subsequent cooling of the core, mantle and crust.

Results

Preliminary studies suggest the following:

i) It is possible to maintain high temperatures, and even eucritic liquids, inside Vesta for 100 Ma after the onset of volcanism. This results from the redistribution of ^{26}Al in the mantle and the crust during core- and crust-forming events, respectively. These episodes cause an 'anomalous' thermal gradient in the asteroid with temperature *decreasing* with depth (see figure), whereas normally in asteroids and planets temperature *increases* with depth. The mantle and crust become hotter than the core which effectively stops heat loss by thermal diffusion from the interior of the asteroid, thereby conserving heat for a longer time than previously expected. ***Hence, an argument against ^{26}Al heating (that it cannot sustain volcanism on Vesta for 100 Ma [9]) is not valid.***

ii) Vesta must have accreted within a time frame of 2.5 +/- 0.5 Ma. If it accreted earlier than this, there would have been whole-mantle melting. Conversely, if it accreted later than this, it would not have been possible to melt silicates.

iii) ^{60}Fe fails to produce any perceptible heating even when iron is sequestered in the core during core formation.

iv) Collisional heating does not make any marked difference in the whole-body thermal history of Vesta. This is because the heat flux from ^{26}Al decay is greater, is spread over a longer timescale, and is distributed uniformly over the whole body, whereas the collisional heat flux is significantly lower, is limited to Stage-1, and is localized to near-surface layers which are most susceptible to loss by radiation.

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Fig.1- END OF STAGE-1

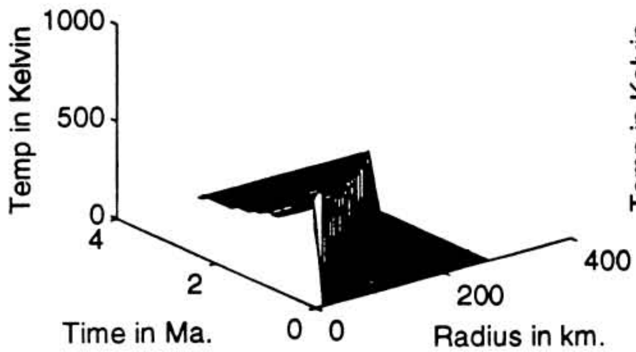

Fig.2- END OF STAGE-2

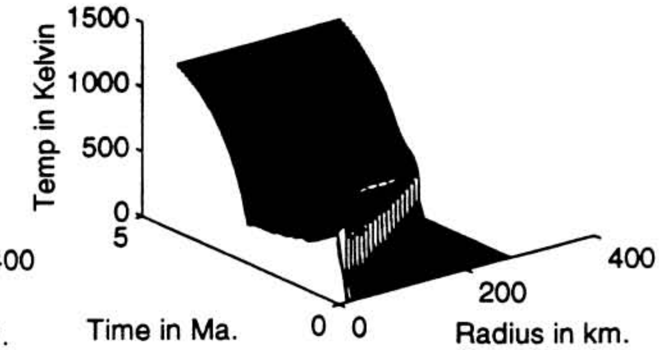

Fig.3- END OF STAGE-3

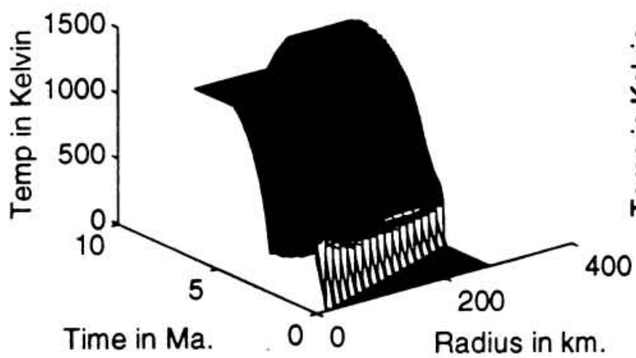

Fig.4- END OF STAGE-4

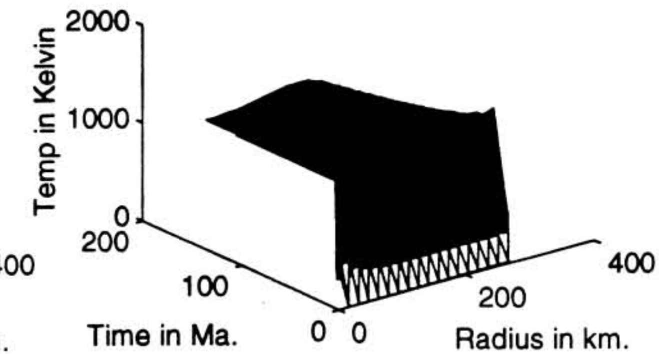

Fig.1 - 4: Temperature - time - radius profiles of Vesta. Note the reverse thermal profile produced after core separation because the mantle becomes hotter than the core due to sequestering of ^{26}Al. A thermal plateau is observed during Stage-1. This plateau may slope down, stay flat or slope up, with increasing time, depending on the rate of accretion at that instant. Another thermal plateau is observed in the core of the Vesta, from the beginning of Stage-3. This is because heat production in the core comes to a halt when ^{26}Al is removed. This plateau gradually dissolves at a later stage due to the influx of heat from a hotter mantle.

References

[1] Papanastassiou D.A., and Wasserberg G.J. (1969) *Earth Planet. Sci Lett. 5,* 361.
[2] Tera F. et al. (1988) *Meteoritics 11,* 513.
[3] Jacobsen S. B. and Wasserberg G.W. (1984) *Earth Planet. Sci.. Lett. 67,* 137.
[4] Lugmair G.W. et al. (1977) *Meteoritics 10,* 447.
[5] Birck L.L. and Allegre C.J. (1978) *Earth Planet. Sci. Lett. 39,* 37.
[6] Carlson R.W. et al (1988) *Lunar Planet. Sci.XIX,* 166.
[7] Takahashi T. and Matsuda J. (1990) *Nature 343,* 540.
[8] Takahashi T. and Matsuda J. (1990) *Meteoritics 29,* 539.
[9] Wood J.A. and Pellas P. (1988) *The Sun in Time,* 74.
[10] Wetherill G.W. (1990) *Ann Rev. Earth Planet. Sci. 18,* 205.
[11] Melosh H. J. (1991) *Origin of the Earth,* 69.
[12] McSween H.Y. et al. (1991) *Icarus 90,* 107-116.
[13] McSween H.Y et al. (1977) *Proc Lunar Planet. Sci. Conf 9th.,* 1437.
[14] Stolper E. (1977) *Geochim. Cosmochim. Acta 41,* 587.