PLANETARY DIFFERENTIATION OF ACCRETING PLANETESIMALS WITH ^{26}Al AND ^{60}Fe AS THE HEAT SOURCES. S. Sahijpal and P. Soni, Department of Physics, Panjab University, Chandigarh, India 160 014 (sandeep@pu.ac.in).

Introduction: Detailed numerical simulations involving linear accretional growth [1] and planetary differentiation of planetesimals with ^{26}Al and ^{60}Fe as the heat sources have been attempted. Contrary to the instantaneously triggered formation of iron-core and eucritic-crust for instantaneous planetary accretion models [2], the growth of iron-core and the extrusion of eucritic melt were evolved progressively according to thermal evolution of accreting planetesimal. Revised estimates of initial ^{60}Fe/^{56}Fe were used [3].

Methodology: Linear accretional growth of planetesimals with H-chondrite composition (Al 1.22 % & Fe 24 %) was considered to commence from a 0.3 km sized body at a time interval (T_{ONSET}) subsequent to the formation of Ca-Al-rich inclusions with canonical value of 5×10^{-5} for ^{26}Al/^{27}Al. Accreting planetesimals gradually attain their final radii of 100–260 km in a time span (T_{ACC}). Heat conduction equation with uniformly distributed ^{26}Al and ^{60}Fe was solved for the planetesimals undergoing accretional growth using finite difference method with constant surface temperature of 300 K [1,4,5]. Temperature variations of specific heat and thermal diffusivity (κ, cm^2/s) were considered [5-7]. Latent heats of melting of Fe-FeS and silicate were also incorporated [1]. A 5 km thick regolith with a thermal diffusivity gradient that falls down by two orders of magnitude compared to the interiors was maintained on planetesimals during their accretional growth and subsequent thermal evolution. Due to the uncertainties involved in the physics of segregation of Fe-FeS melt from bulk silicate, two alternative scenarios have been proposed. These include segregation of Fe-FeS from bulk silicate at 1213-1233 K [2], or alternatively, the initiation of Fe melt segregation at higher temperature (≥ 1450 K), once the bulk silicate melt fraction exceeds ~0.4 [8]. Thermal models based on these two alternative scenarios have been recently worked out in details till the iron-core formation stage [9]. In the present work, the Fe-FeS melt segregation initiates at 1213–1233 K. The melt descends towards the center of planetesimal to form iron-core (Fe ~90 %) that grows in size according to the thermal evolution of planetesimal. The differentiation results in redistribution of ^{26}Al and ^{60}Fe. Simulations were run further to access whether eucritic melt could be initiated at ≥ 1450 K. ^{26}Al-rich eucritic melt was removed from the silicate melting regions during their initial 20% melting. The ascend of ^{26}Al-rich eucritic melt was parametrically modeled to acquire any suitable melt percolation velocity. In the present work, the melt migration velocity was assumed to be minimum (occurring over a timescale of ~1Ma). This extreme scenario results in enhanced heating and melting of the interiors due to the slow ascend of ^{26}Al-rich melt.

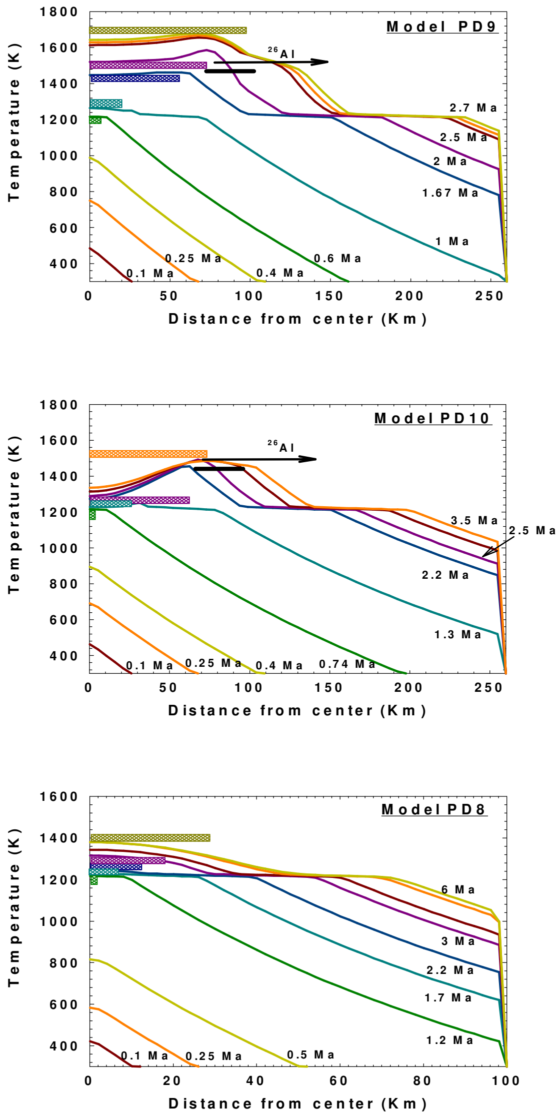

Figure 1. Thermal profiles for three planetary differentiation models (see table 1. for details). Hatched bars represent growth of Fe-FeS core.

Results and Discussions: The results obtained for a set of simulations along with the various simulation parameters are presented in table 1. In each case the simulation was run for the maximum timespan mentioned. Thermal profiles along with the growth of iron-core corresponding to three planetary differentiation models are graphically presented in figure 1. Within the used set of simulation parameters, some of the salient features of the simulations are:

1) In order to have significant silicate melting to produce eucritic melt, the onset of planetesimal accretion should occur within 1.5 Ma from the time of formation of Ca-Al-rich inclusions having canonical value of $^{26}Al/^{27}Al$. Higher silicate melt fractions require even smaller T_{ONSET} ($\leq$ 1 Ma).
2) For the linear accreting models of planetesimals, the growth of Fe-FeS core occurs steadily contrary to instantaneous accreting models [2]. Subsequent growth of iron-core can occur along with silicate melting and crustal growth.
3) For T_{ONSET} ~ 2Ma, iron-core can grow to a significant extent. However there will be no eucritic crustal growth in this scenario.
4) Simulation (PD10) with a lower $(^{60}Fe/^{56}Fe)_{initial}$ shows an inverse thermal gradient within the growing iron-core, whereas, there is an insignificant inverse thermal gradient in the case of simulation (PD9) with a higher $(^{60}Fe/^{56}Fe)_{initial}$. The exact estimate of $(^{60}Fe/^{56}Fe)_{initial}$ in the early solar system will thus play an important role in deducing the thermal evolution of planetesimals specifically in the case where ^{26}Al-rich eucritic melt percolation velocity is high compared to that used here. Rapid removal of ^{26}Al from inner regions can cease further heating and melting in the interiors in case the abundance of ^{60}Fe is low.
5) Even in the present scenario where ^{26}Al-rich eucritic melt percolation velocity is slow, the melt can ascend to form crust within ~ 1 Ma, and can result in eucritic crustal growth well within 5 Ma [10] from the time of formation of Ca-Al-rich inclusions.

Conclusions: It seems quite likely that planetesimal accretion and initiation of planetary differentiation occurred over timescales inferred from (^{26}Al-^{26}Mg) chronometeric ages [11] of chondrules.

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Table 1. Planetary differentiation models for planetesimals with different accretion rates and accretion onset times.

Model	Radius of Planetesimal	T_{ONSET} (Ma)*	T_{ACC} (Ma)	Onset of Fe-core formation (Ma)	Iron-core size (at Ma) *Sequential growth* ➔	Eucritic melt^{ϒ} (at Ma)	Silicate melt Fraction$^{£}$
PD1	100	1	1	0.4	20(1) – 34(1.5) – 42(1.9)	12(0.7) – 36(1.5)	0.4
PD2	100	1	1.5	0.4	14(1) – 24(1.5) – 30(1.9)	10(0.75) – 26(1.5)	0.4
PD3	100	1	2	0.4	10(1) – 18(1.5) – 22(1.9)	10(0.8) – 20(1.5)	0.4
PD4	100	1.5	1	0.6	8(1) – 26(1.5) – 40(3)	28(1.6) – 42(3)	0.2
PD5$^{\$}$	100	1.5	1	0.8	12(1.5) – 20(2) – 30(3)	22(2) – 32(3)	0.15
PD6	100	1.5	1.5	0.7	6(1) – 20(2) – 28(3)	16(1.55) – 30(3)	0.15
PD7	100	1.5	2	0.7	4(1) – 16(2) – 22(3)	14(1.7) – 24(3)	0.15
PD8	100	2	1	1.2	12(2.2) – 18(3) – 28(6)	No melt	0.0
PD9	260	1.5	1	0.6	21(1) – 73(2) – 104(3)	68(1.75) – 109(3)	0.2
PD10$^{\$}$	260	1.5	1	0.8	42(1.7) – 62(2.5) – 78(3.5)	63(2.2) – 83(3.5)	0.15
PD11	260	2	1	1.2	26(2) – 47(3) – 57(4)	No melt	0.0

*T_{ONSET} (Ma, million years) is the time of initiation of the formation of planetesimal from the time of formation of CAIs. All other timescales are with respect to T_{ONSET}.

All distances (in km) are measured from the center of planetesimal.

$(^{26}Al/^{27}Al)_{initial}$ ~ 5×10^{-5} and $(^{60}Fe/^{56}Fe)_{initial}$ ~ 10^{-6} at the time of formation of CAIs.

$^{\$}$ Simulations with $(^{26}Al/^{27}Al)_{initial}$ ~ 5×10^{-5} and $(^{60}Fe/^{56}Fe)_{initial}$ ~ 2×10^{-7} at the time of formation of CAIs.

^{ϒ} Eucritic melt generated at a specific distance from the center of planetesimal.

$^{£}$ Silicate melt fraction in regions where melting of silicate commence.

SIMULATION PARAMETERS

Specific heat (melt) ~ 0.48 cal/g/K

κ (Iron) ~ 0.05 cm^2/s

Solidus Fe-FeS = 1213 K Silicate = 1450 K

Liquidus Fe-FeS = 1233 K Silicate = 1840 K

Latent heat of melting 64 cal/g (Iron) 100 cal/g (silicate);