THE EFFECT OF EARLY ACCRETION AND REDISTRIBUTION OF $^{26}$Al ON THE THERMAL EVOLUTION OF MARS. A. Ghosh1, F. Nimmo2 and H. Y. McSween, Jr3. 1Planetary Geosciences Institute, Department of Geological Sciences, University of Tennessee, Knoxville, TN 37996-1410. 2 Dept Earth Sciences, University College London, Gower St, London WC1E 6BT, UK. Email: aghosh@cs.utk.edu.

Introduction:

Thermal models of Mars provide insights into a wide spectrum of questions related to the evolutionary history of Mars like the processes of core, crust and mantle separation, duration of the Martian dynamo and formation of the hemispherical dichotomy and the Tharsis region [1]. We evaluate for the first time the effect of $^{26}$Al, and its redistribution during differentiation, on the early thermal evolution of Mars.

Earlier accretion models of Mars [e.g. 2, 3] estimate a timescale of accretion of Mars between 100 – 1500 Myrs. Most thermal models [e.g. 1] have retained the assumption of ~100 Myr accretion timescale, and consequently have considered heating by long-lived radionuclides. Theoretical support for rapid accretion was provided by recognition of “runaway growth,” that allowed bodies in a planetesimal swarm to attain large sizes before velocities are stirred up, in a shorter interval of time than previously recognized [4, 5]. Plausible swarm parameters in recent accretion models [3, 6] allow runaway embryos to grow as large as Mars on a timescale ~1 Myr or a hundredth of the time thought by [7, 8]. Also, recent Hf-W systematics of SNC meteorites [e.g. 9, 10] have revised preexisting chronometric estimates of accretion times to much lower values. [9] suggest that the main growth stage of terrestrial planets ended within 10 Myrs. Other than the relative timing of accretion with respect to CAI formation, the postaccretionary temperature profile, depends on multiple factors. We explored the effect of accretion on the thermal history of Mars using collisional heating and shortlived radionuclides and demonstrated that the post accretionary temperature profile in the Martian interior depends on accretionary timescales[11]. Similarly, the effects of core formation during accretion plays a role in determining the heat budget of early Mars [12].

Mars Global Surveyor observations of the Martian magnetic field show strong anomalies concentrated in the ancient southern highlands [13]. A possible interpretation of these observations is that early Mars possessed a geodynamo for the first 500 Myrs. Core convection, necessary for the geodynamo to operate, requires a high heat flux out of the core. One way of achieving such a high heat flux is if the mantle cools efficiently owing to plate tectonics [14]. In this study, we explore whether $^{26}$Al (and the partitioning of Al during crust-mantle differentiation) influence the thermal and geomagnetic evolution of Mars.

Methods:

Accretion is assumed to initiate 2 Myrs after CAI formation [15]. Two model calculations are made to bracket upper and lower limits of accretion time: Mars is thus assumed to accrete in 1 and 10 Myrs., respectively. Accretion is assumed to be instantaneous. The simulation initiates after accretion is complete. Mars is assumed to be partitioned into a core and mantle with an initial temperature of 2000 K. Specific heat of the core and mantle are taken to constant at 840 J/kg/K and 1200 J/kg/K, respectively. The heat flux from the mantle in a plate tectonics regime is approximated from [14, 16]. The core is assumed to be isothermal. Heating is assumed to take place by short-lived ($^{26}$Al, $^{60}$Fe) and long-lived (K, U, Th) radionuclides. The Al content of the crust was approximated from the composition of Martian dust as measured by Mars Pathfinder [17]. The Al content of the undifferentiated mantle after core formation and the bulk planet were approximated from geochemical models of [18]. Viscosity is assumed to be temperature dependent with a reference viscosity of $10^{20}$ K at 1573 K [14].

Results and Discussion:

The interior of early Mars is believed to have undergone uniform heating and has been the basis of uniform initial temperature assumptions in Mars thermal models. However, redistribution of radionuclides during differentiation may cause inhomogeneous heating of the crust and mantle particularly when $^{26}$Al is potent. Thus, $^{26}$Al and $^{60}$Fe will be partitioned into the mantle and core, respectively after core formation, causing the mantle temperature to increase significantly compared to the underlying core. A plate tectonic regime (without $^{26}$Al) is thought to drive core convection as shown by [14]. However, in the case of a hotter mantle overlying the core, core convection is unlikely to occur. A plate tectonic regime must first lose excess heat released by $^{26}$Al decay, until the mantle is cooler than the core. At such time, core convection can initiate causing a magnetic field on Mars. Thus, the onset of a magnetic field and of the plate tectonic episode on Mars would not be simultaneous but staggered in time, in a scenario of fast accretion. If the duration of accretion of Mars is ~10 Myrs., plate tectonics does drive core convection from the outset as shown previously by [14].

Fig. 1: The plots summarizes core and mantle temperatures as a function of time with respect to CAI formation with (a) and without (b) including the effect of $^{26}$Al, respectively. The first 100 Myrs are shown in order to highlight the effect of $^{26}$Al on the early evolution of Mars. A plate tectonic regime is assumed to have existed for the mantle: hence, heat loss from the mantle is quick. Time is shown in Myrs. and temperature in K. The accretion of Mars is assumed to be complete 3 Myrs after CAI formation. Note that the temperature of the mantle sharply increases at the early stages of the simulation due to preferential heating of the mantle by $^{26}$Al, in case of (a). At this time, the mantle is hotter than the underlying core, and the core is assumed to gain heat by conduction from the overlying mantle. In a scenario, where $^{26}$Al is not considered (b), the temperatures of the mantle and core decrease monotonically as was shown by [14].

(a) With $^{26}$Al heating