POTASSIUM IN THE MARTIAN CORE: IMPLICATIONS FOR AN EARLY DYNAMO. J-. P. Williams[1] and F. Nimmo[2], [1] Dept. Earth and Space Sciences, University of California, Los Angeles, CA 90095, jpierre@mars.ucla.edu, [2]Dept. Earth Sciences, University College London, Gower St, London WC1E 6BT, UK, nimmo@ess.ucla.edu.

Abstract: Planetary geodynamo are driven by thermal or compositional convection in the core. Mars is thought to have possessed a geodynamo which ceased ~0.5 Gyr after the formation of the planet. A possible, but ad hoc, explanation for this behavior is is an early episode of plate tectonics, which drove core convection by rapid cooling of the mantle. In this paper we examine an alternative scenario: that the Martian core contains several hundred ppm potassium. The radioactive decay of ^{40}K provides an extra source of energy to power an early dynamo; its short half-life (1.25 Gyr) ensures that the dynamo will stop early in the planet's history. Recent experimental results suggest that the potassium is likely to partition into the core at the relatively low pressures and high sulfur contents appropriate to Mars [1,2,3]. Thus, the presence of potassium in the Martian core provides a natural explanation for the geodynamo behavior without needing to invoke plate tectonics. Our results also suggest that core solidification is unlikely to have occurred, since this would probably prolong the geodynamo for several Gyr. If the core is entirely liquid, this places a lower bound on sulfur content of ~5 % by weight.

Introduction: Strong, linearly magnetized regions of the Martian crust discovered by the Mars Global Surveyor (MGS) Magnetometer/Electron Reflectometer (MAG/ER) investigation [4,5], indicate the presence of an earlier epoch in which Mars possessed a dynamo. The majority of the magnetized crust is in the ancient, heavily cratered terrains in the southern hemisphere. Their absence in and around the large impact basins of Argyre and Hellas imply the Martian dynamo had ceased by the time these impact events occurred, constraining this period to within the first ~500 million years of the planets history [6].

Previous work shows that an early phase of plate tectonics transitioning into a stagnant lid regime could provide the appropriate heat flux out of the core to drive an early, short-lived dynamo [7]. However, strong evidence for plate tectonics having occurred is lacking. Inner core solidification causes compositional convection [8, 9] but requires a sulfur content lower than considered geochemically plausible [10,11] and is unlikely to produce the short geodynamo duration. Radiogenic heating in the core provides an explanation for an early, brief dynamo without invoking the speculative hypothesis of plate tectonics.

Model Description: Our thermal evolution model is based on that of [7], which calculates the core and mantle thermal evolution assuming stagnant lid convection is operating. The core parameters adopted are discussed below; we assume that the core remains liquid throughout. We calculate the rate of entropy production within the core as a function of time using the methods of [12] and [13]. The rate of entropy production required to drive the geodynamo is not known; here we assume that any value in excess of the conductive value is sufficient (see Fig 1).

Martian Core: Properties of the Martian core are constrained by analysis of the Martian meteorites [10, 11], and the planet's mass and moment of inertia [14] although uncertainties in the core density and size remain as these quantities depend on the interior temperature profile and light element abundance. Further, it is unclear how the thermal expansivity varies with depth in the core and this will affect the adiabat. Recent results by Yoder et al. [15] from MGS radio tracking data indicate the core is at least partially liquid, with an inferred radius between 1520 and 1840 km.

Model Results: Figure 1 show our results for a nominal case for Mars with a core sulfur content Fe - 14.2 wt% S and initial core and mantle temperatures of 2800 K. Figures 1A and B show the case with no potassium in the core. Though ΔE is maximum early in the core history from the initially higher heat flux out of the core, it never exceeds the conductive threshold, and the geodynamo will thus not operate. With the addition of 400 ppm potassium to the core (Figure 1C and D), it can be seen that the entropy production is now sufficient to drive an early dynamo during the first ~500 Myr. The heat fluxes after 4.5 Gyr are similar because ^{40}K has decayed.

Discussion: Our model demonstrates that the addition of potassium in the core provides a heat source capable of generating the power required to drive a dynamo in a liquid Martian core and provides an explanation for its termination within the first 500 Myr of the planet's history. Future work will explore the effects of varying the initial temperatures of the core and mantle, and the viscosity structure of the mantle.

Our results also suggest that the core is entirely liquid as solidification of an inner core is likely to generate a dynamo with a duration of several Gyr. This places a lower bound on the core sulfur content.

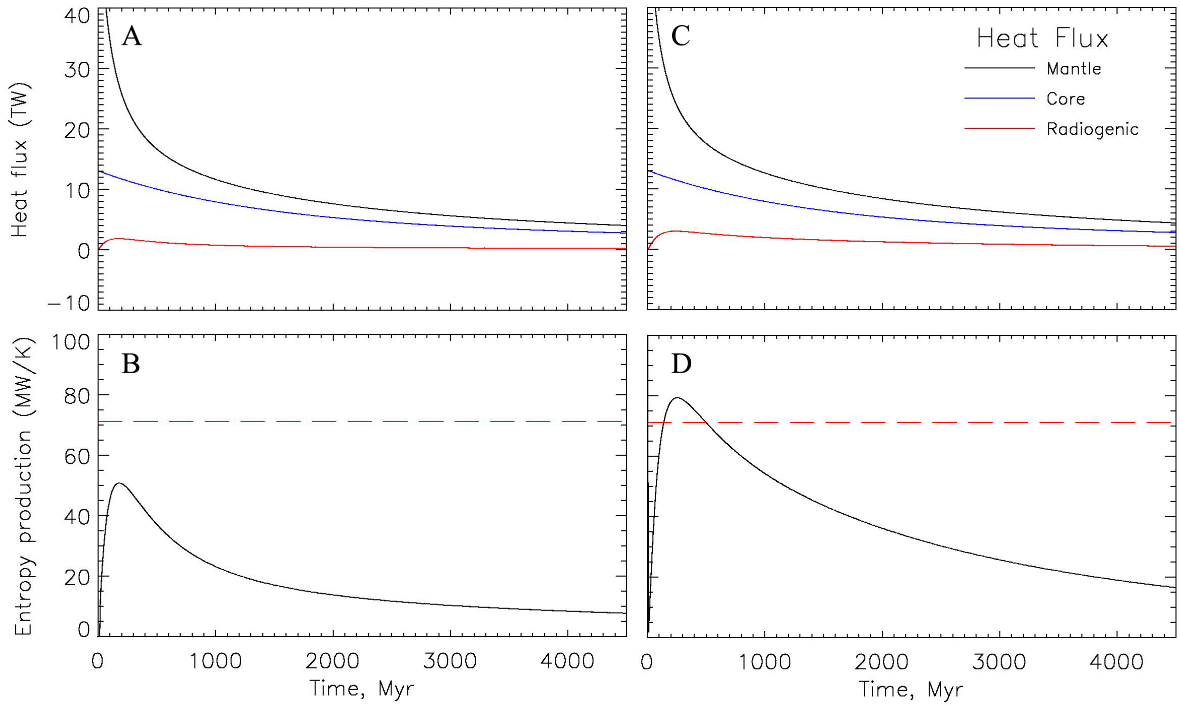

Figure 1. Model results showing mantle and core heat fluxes with mantle radiogenic heat production, and core entropy production for liquid Martian core with 14.2 wt% sulfur. A and B) The Core contains no potassium. C and D) with the addition of 400 ppm potassium in the core, excess entropy production drives dynamo that ceases at ~500 Myr. Solid line denotes the rate of entropy production ΔE with time. Dashed line denotes the minimum (conductive) entropy production required to drive a geodynamo.

Comparisons of experimental high pressure melting curves for iron and iron sulfide mixtures [15, 16] with corresponding adiabats for the core indicates the liquid core must contain > 5 wt% S. Models based on the chemistry of SNC meteorites [10, 11] estimate a core sulfur content of ~15 wt%, placing the adiabat well above the empirical melting temperatures.

References: [1] Gessmann C. K. and Wood B. J. (2002) *EPSL*, *200*, 63-78. [2] Murthy et al. (2002) submitted to *Science*. [3] Lee K. K. and Jeanloz R. (2002) *EOS Trans. Am. Geophys. Union,. 83*(47) Abstract #MR62B-1065. [4] Acuna M. H. et al. (1999) *Science*, *284*, 790-793. [5] Connerney J. E. P. et al. (1999) *Science*, *284*, 794-798. [6] Strom R. G. et al. (1992) in *Mars* Ed. Kieffer et al. UA press. [7] Nimmo F. and Stevenson D. J. (2001) *JGR*, *105*, 11,969-11,979. [8] Stevenson D. J. et al. (1983) *Icarus 54*, 466-489. [9] Spohn T. et al. (1998) *Astron. Astrophys. Rev.*, *8*, 181-236. [10] Longhi J. et al. (1992) in *Mars* Ed. Kieffer et al. UA press. [11] Wänke H. and Drebus (1988) *Phil. Trans. Roy. Soc. London, A235*, 545-557. [12] Gubbins D. et al. (1979) *Geophys. J. R. Astro. Soc.*, *59*, 57-99. [13] Nimmo F. et al. (2003) *Geophys. J. Int., submitted*. [13] Folkner W. M. et al. (1997) *Science*, *278*, 1749-1751. [14] Yoder C. F. et al (2003) *Science*, *300*, 299-303. [15] Boehler R. (1986) *GRL*, *13*, 1153-1156. [16] Fei Y. et al. (2000) *Am. Mineral.*, *85*, 1830-1833.