THE COUPLING BETWEEN THE DYNAMO SHUTDOWN AND THE WATER ABUNDANCE ON MARS: THE MANTLE FILTER. C. Sotin[1], J-P. Bibring[2], G. Choblet[1] and F. Couturier[1], [1]University of Nantes (Faculté des Sciences, 2 rue de la Houssinière, 44322 Nantes, France), [2]Institut d'Astrophysique Spatial (IAS, Université d'Orsay, Bât. 120-121, 91405 Orsay, France).

Introduction: The OMEGA imaging spectrometer onboard the MarExpress spacecraft has found two kinds of hydrated minerals on the Martian surface, which suggests two episodes of water content on the Martian surface. The formation of phyllosilicates is compatible with abundant water while the presence of sulfates requires acid pH. In the same period of time, the Martian dynamo stopped. This study investigates how heat transfer in the Martian mantle may explain the dynamo shutdown and the late release of water in the Martian atmosphere.

In the absence of plate tectonics, convection in the Martian mantle is in the so-called stagnant lid regime where cold downwellings form below a thick conductive lid. The geometry of convection is important to understand in order to evaluate the amount of water that can be released from the mantle. In the case of a fluid heated from within and cooled from above, only cold downwellings are present [1]. If the mean mantle temperature is large enough, partial melt is widespread and can provide global volcanism or plutonism.

Hot upwellings may eventually form at the core-mantle boundary if the temperature difference between the core and the mantle is large enough to produce these instabilities. In that case, partial melt is located within the hot plumes at a deeper depth. Partial melt would cause localized volcanism. This process can last as long as the temperature difference between the core and the mantle is large enough to trigger instabilities. This study investigates the amount of heat that is released from the core and compares it to the amount of heat that was stocked in the core during the accretion process. We are using 3D spherical calculations to determine the scaling laws appropriate for a fluid having temperature-dependent viscosity.

Gravitational energy: Gravitational potential is modified as Mars differentiated into a denser inner core and a lighter mantle [2]. In a simple two-layer model, the total energy released by gravitational rearrangement is:

$$\Delta E = 16\pi^2 G\left(\int_0^R \rho_2(r).r\left\{\int_0^r \rho_2(r')r'^2.dr'\right\}.dr - \int_0^R \rho_1(r).r\left\{\int_0^r \rho_1(r')r'^2.dr'\right\}.dr\right)$$

with $\rho_2(r') = \rho_c$ for $r' < R_c$, $\rho_2(r') = \rho_m$ for $R_c < r' < R$, and $\rho_1(r') = \rho$. Assuming that this change of gravitational energy is uniformly transferred into heat ($M.C_P.\Delta T=\Delta E$), the temperature increase is between 300 and 400 K [2]. However, the temperature increase is not equally partitioned between the core and the mantle. Although no detailed calculations have been performed, one end-member model is to consider that all the gravitational energy change is transformed into heating the iron core (Table 1).

Core radius (km)	2100	1900	1500
Core density	5.724	6.281	8.445
Mantle density	3.375	3.431	3.505
Excess gravitational energy (10^{30} J)	0.242	0.248	0.262
Mean temperature increase (K)	378	386	408
Core temperature increase (K)	1071	1363	2185

Table 1: Results of the energy involved in the differentiation and the heating of the core.

Geochemical arguments coming from the study of the SNC meteorites suggest that the core differentiation occurred in less than 30 My. This time is short compared to the time required to heat up the mantle by the decay of the long-lived radiogenic elements. The following section describes models of convection that are performed to assess the time required to cool the core.

Instability at the core-mantle boundary: Assuming that the temperature difference between the core and the mantle is large (Table 1), thermal instabilities can happen. Following the study by Whitehead and Luther [3], Sotin et al [4] have studied the onset time for the formation of the plume and the number of plumes formed as a function of the temperature difference between the core and the mantle. In the results showed in Figure 1, the mantle viscosity is supposed to be equal to 10^{21} Pa.s at T=1900 K with an activation energy of 350 kJ/mole. If the mantle temperature is equal to 1500 K, then only one plume is formed, which implies either a temperature difference of 400K and an onset time of 400 My or a temperature difference of 500 K and onset time lower than 200 My. If the temperature difference is smaller than 300 K, then the onset time is larger than 1 Gy.

The formation of only one plume is interesting since it would correspond to the formation of Tharsis. Although this possibility is within the set of possible models, it must be noted that there are very large uncertainties concerning the parameters and that models with several plumes are (more) likely. For a given core temperature, the larger the mantle temperature, the smaller the temperature difference and the larger the number of plumes (Fig. 1).

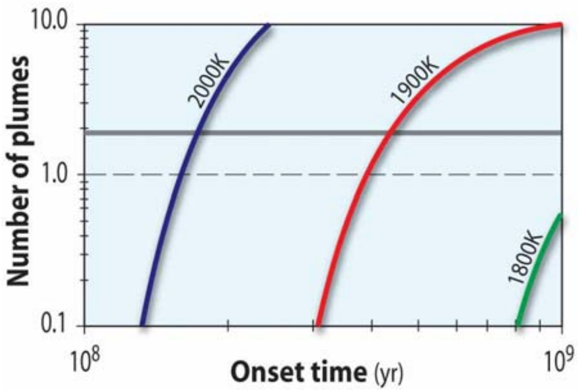

Figure 1: number of plumes forming at the core-mantle boundary as a function of the onset time of convection.

The next question that needs to be addressed is how much heat is transferred at the core mantle-boundary. Using the numerical work of Deschamps and Sotin [5], we can assess the maximum amount of heat that can be transferred by convection when a stationary regime is achieved. This estimate does not take into account the interaction with the downwelling plumes that form at the cold thermal boundary layer below the conductive lid.

The next question is how long does it take for mantle convection to cool the core such that the temperature difference between the core and the mantle does not allow for further cooling of the core and therefore is not large enough for maintaining a dynamo. Numerical simulations suggest that the amount of heat at the core-mantle boundary is on the order of 1 TW. So it would take a few hundreds of My to remove the heat that was accumulated during the differentiation process. The existence of a magnetic dynamo would be limited to this period as previous studies already suggested. It has been proposed that once the dynamo stops, water would disappear due to the lack of a magnetic shield.

Instability below the conductive lid: Once the temperature difference between the core and the mantle is not large enough to generate hot plumes, the heat transfer will be achieved by subsolidus convection driven by thermal instabilities below the conductive lid. The long-term evolution of the mantle temperature can be addressed by using scaling laws that have been developed for a fluid having complex viscosity. An example of such calculation is presented in Figure 2. It can be noted that in the conductive lid regime, the convection is not vigorous enough to extract the radiogenic heat during the first billion years. The mantle temperature increases as well as the heat flux and a maximum is achieved around 800 My. This peak could correspond to the Noachian-Hesperian limit and/or to a maximum of volcanism and water release. Then, the decrease of the radiogenic heating would lead to the cooling of the mantle. But the cooling is very slow and the present temperature would still be pretty high (1600 K).

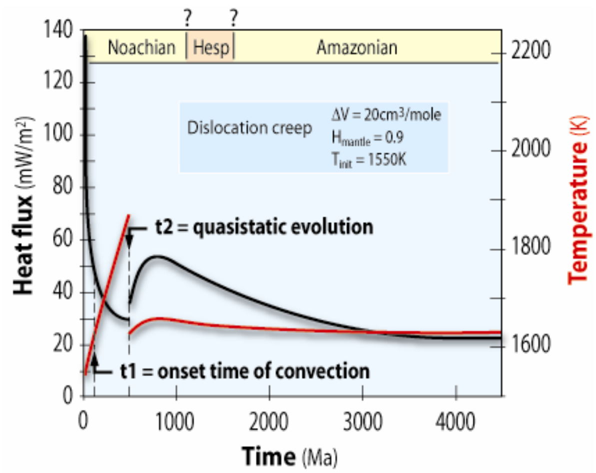

Figure 2 : Example of temperature and heat flux evolution.

Conditions compatible with the formation of sulfates suggest a late episode releasing some water in the atmosphere. This late release could be the end of the partial melt in the mantle or the formation of a last hot plume at the core-mantle boundary.

Conclusions: Thermal evolution models suggest that the present temperature of the Mars' mantle is similar to the temperature of the Earth's mantle and that the core is still liquid. Because the mantle is overlaid by a thick conductive lid, the heat flux is just large enough to evacuate the heat produced by the decay of the radiogenic elements. Convection is driven mostly by cold downwellings. The mantle temperature is not large enough to partially melt the mantle.

Such models have to await seismic measurements to be confirmed. There are important to understand the evolution of Mars and the fate of water.

References: [1] Parmentier E.M., Sotin C. and Travis B.J. (1994) *Geophys. J. Int, 116*, 241-251. [2]

Solomon (1979) *Phys. Earth Planet. Int.*, *19*, 168-182. [3] Whitehead J.A. and Luther D.S. (1975) *J. Geophys. Res.*, *80*, 705-717. [4] Sotin C., Head J.W. and Parmentier E.M. (2002) *LPSC XXXIII*, Abstract #1922. [5] Deschamps F. and Sotin C. (2000) *Geophys. J. Int.*, *143*, 204-218.