DEEP HYDROTHERMAL CIRCULATION AND IMPLICATIONS FOR THE EARLY CRUSTAL COMPOSITIONAL AND THERMAL EVOLUTION OF MARS. E.M. Parmentier, J.F. Mustard, B.L. Ehlmann, and L.H. Roach, Department of Geological Sciences, Brown University, Providence, RI, 02912 (EM_Parmentier@brown.edu).

Introduction: Both orbital remote sensing and geophysical observations may indicate an important role for hydrothermal crustal cooling during the Noachian epoch. Here we summarize these individual constraints on thermal structure and explore their combined implications for the depth and vigor of hydrothermal circulation during the early crustal evolution of Mars.

Orbital remote sensing shows that phyllosilicate minerals are common in Noachian-aged terrains but have not been observed in younger terrains (<3.8 Ga) [1]. Throughout the Noachian highlands, phyllosilicates are observed in deeply eroded terrains as well as in association with impact craters, in their walls, rims, ejecta, and in central peaks of craters as large as 45 km, corresponding to excavation depths of 4-5 km [2,3,4]. CRISM and OMEGA mapping typically show phyllosilicate-bearing rocks occupy the lowest observable stratigraphic unit, and the most common alteration minerals are iron magnesium smectites which typically form at low pressures and temperatures <200°C. Widespread occurrences of phyllosilicates to depths of at least 4-5 km may provide evidence for deep crustal hydrothermal circulation during the Noachian.

Faulting and gravity anomalies associated with topographic loads indiate elastic lithosphere thicknesses a large as ~30 km near the end of the Noachian. The inferred variation of surface heatflux as a function of age for various regions of Mars is shown in Figure 1. For reasonable thermal conductivities of 2-3 W/m-^{o}C-s, a surface heat flux in the range 20-40 mW/m^2 correponds to an elastic thickness of 30 km. Relaxation of elastic stresses due to thermally activated creep results in an elastic lithosphere thickness that is sensitive to crustal temperatures, particularly to temperatures in the upper part of the crust that depend on both the heat flux and thermal conductivity of fractured crustal rock. For a given age, the range of heat flux indicated can be attributed in part to local thermal conditions at the time of faulting or loading. High heat fluxes or small thickness are often associated with heating due to concurrent igneous activity, as appears to be the case in the areas of rifting (7) and (8) of Figure 1, in contrast to thrust faulting in (4). Thus the lowest heat fluxes or largest thicknesses should reflect regional thermal conditions.

Plausible planetary thermal evolution models with chondritic abundances of heat producing elements [13,14] predict a surface heat flux of 50-60 mW/m^2 near the end of the Noachian [12]. Other models for the concentration of heat producing elements in Mars

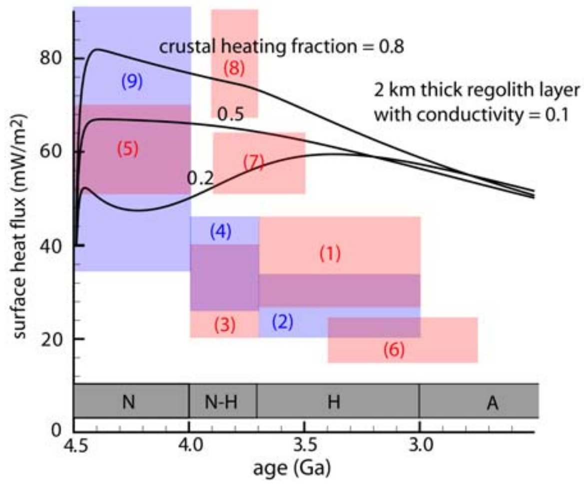

Figure 1. Surface heat flux as a function of age inferred from surface topography due to faulting and the flexural admittance gravity-topography for indicated areas of Mars shown by shaded boxes. (1) N. Plains [5]; (2) Solis Planum [6]; (3) Hellas rim [6]; (4) Thaumasia [7]; (5) Amenthes [8]; (6) Valles Marineris [9]; (7) Coracis Fossae [10]; (8) Acheron Fossae [11]; (9) Highlands [6]. Solid curves show surface heat flux predicted by thermal evolution model [12] for chondritic heat production with different fractions partitioned into a 50 km-thick crust.

[15] would result in an even higher surface heat flow, particular in the early evolution. Predicted surface heatflux also depends on the fraction of heat producing elements in the crust. Even for a relatively low crustal heating fraction, the predicted heat flux for planetary cooling is significantly greater than the lower values inferred from elastic lithospheric thickness, suggesting that a significant fraction of heatflow reaching the surface may be transported by hydrothermal convection rather than by conduction alone.

Relaxation of crustal thickness variations occurs in response to lower crustal flow (inset Figure 2). Creep of the lower crust causes flow away from regions of thick crust and is sensitive to both the temperature and geothermal gradient at the crust-mantle boundary. Note, in contrast, that elastic thickness variations which are sensitive primarily to temperatures in the upper crust. Thus elastic thickness and relaxation crustal thickness variations give independent information on crustal thermal structure.

Estimates of relaxation rate [12] indicate that crustal thickness variations created during the Noachian would not be preserved to the presentday in the presence of lower crustal flow in a 50 km thick crust with a wet diabase rheology. Figure 2 shows that the relaxation rate with heat flux due only to conduction (curve with *Nu*=1) is too high to preserve late-Noachian crustal thickness variations. If a low conductivity brecciated crustal layer (regolith) is present, even a much more creep-resistant dry diabase rheology would not preserve crustal thickness variations. Other curves in Figure 2 show the predicted effect of hydrothermal cooling on crustal relaxation rates, where *Nu* is the ratio of ratio hydrothermal heat flux to the conductive heat flux. Nusselt number is proportional to Rayleigh number $Nu \propto Ra = \rho\alpha\Delta TgKD/\mu\kappa$ [cf. 16]. Here physical properties ρ, α, κ, and μ are the density, thermal expansion coefficient, thermal diffusivity, and fluid viscosity (water), respectively; and ΔT, K, and D are the temperature difference, permeability, and thickness of the fluid saturated rock layer.

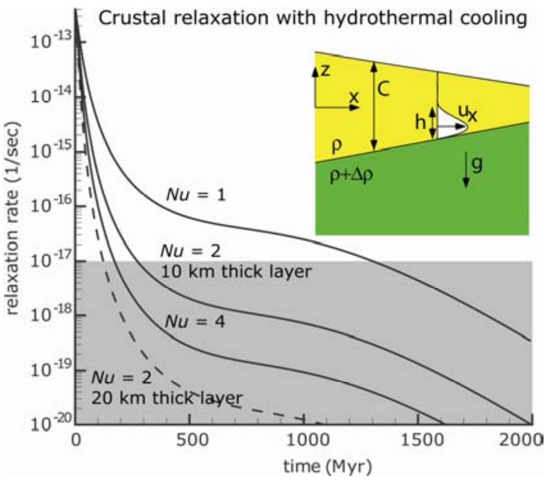

Figure 2. Effect of hydrothermal cooling on the relaxation rate of crustal thickness variations due to thermally-activated creep near the base of a wet-diabase crust. Hydrothermally-cooled layer thicknesses of 10 and 20 km are assumed for solid and dashed curves, respectively. Relaxation rates must be less than about 10^{-17}/sec (within the shaded region) to preserve crustal thickness variations to the present day, thus requiring hydrothermal cooling.

A hypothetical crustal thermal structure with hydrothermal cooling is shown in Figure 3. The thermal structure is controlled primarily by *K* and *D*. Larger values of *K*, and correspondingly larger *Nu*-values, result in thinner thermal boundary layers and a larger central isothermal region. Relative to the purely conductive temperature distribution that reaches a temperature corresponding to an elastic-ductile transition at ~30 km depth, the hydrothermal profile allows higher geothermal gradients at shallow depth. Thus the hydrothermal geotherm can satisfy both the geophysical constraints on elastic thickness and provide an explanation for mineralogical data indicating Fe-Mg smectites at up to 5 km depth. The geotherm shown corresponds to *Nu* ~3 and thus satisfies the upper bound constraint on the preservation of Noachian-aged crustal thickness variations.

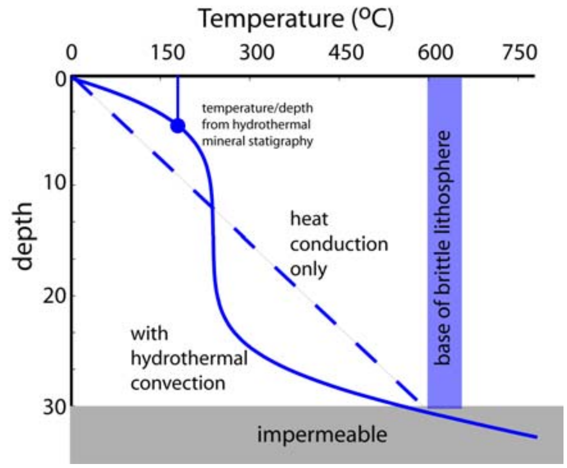

Figure 3. Hypothetical crustal thermal structure with hydrothermal cooling consists of relatively uniform temperature where heat is transferred convectively between conductive thermal boundary layer at the top and bottom. In this case the surface thermal gradient is about twice the purely conductive gradient (dashed line) corresponding to *Nu* ~ 3.

In addition to the average value of *K*, the form of the thermal structure will depend on the variation of permeability with depth in the crust: permeability that decreases with depth will increase the thickness of the lower TBL. The thickness of the upper TBL will be controlled by the distribution of surface discharge and recharge. Temperature differences between regions of discharge and recharge may correspond to predictable variations in mineralogy; and the distribution of these regions on the surface may control the detectabilty of such mineralogical variations in orbital observations.

The results obtained thus far, as presented here, show that combined geophysical and mineralogical observations may provide important constrains on hydrothermal cooling of the early crust.

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