INFERRING MAXIMUM HEAT FLUX BENEATH INSIGHT LANDING SITE FROM DEPTH OF PORE CLOSURE.

S. Gyalay[1] , F. Nimmo[1], A.-C. Plesa[2], and M.A. Wieczorek[3], [1]University of California Santa Cruz, Santa Cruz, CA 95064, USA (sgyalay@ucsc.edu), [2]German Aerospace Center (DLR), Berlin, Germany, [3]Observatoire de la Côte d'Azur, Nice, France.

Introduction: By modeling viscous pore closure through our Moon's thermal history, [1] estimated that there should be a transition from porous to pore-free crust 40-85 km below the lunar surface. This is consistent with localized gravity-topography studies of the lunar crust, which found an increase in density with depth in the lunar highland terrains, consistent with a pore-closure model [2]. The *InSight* lander on Mars may also be capable of detecting such an interface, from which we can place constraints on the maximum past heat flux experienced at that location.

Viscous Pore Closure: Following [1], how quickly the porosity φ of regolith closes over time t depends on the overburden pressure P and dynamic viscosity η:

$$\frac{d\varphi}{dt} = -\varphi\frac{P}{\eta} \tag{1}$$

Viscosity depends on stress and rheological constants A, n; an activation energy Q, and the gas constant R:

$$\eta = \frac{P^{1-n}}{A}e^{Q/RT} \tag{2}$$

Assuming temperature remains constant, one can solve the above differential equation to find that porosity changes from an initial porosity φ_0 over some elapsed time as:

$$\varphi = \varphi_0 e^{-Pt/\eta} \tag{3}$$

Assume that pores close at a critical porosity φ_C. The critical pore-closure temperature T_C is:

$$T_C = \frac{Q}{R\ln\left(\frac{tP^nA}{\ln(\varphi_0/\varphi_C)}\right)} \tag{4}$$

This expression shows that the closure temperature is strongly dependent on the activation energy Q and weakly dependent on the overburden pressure and elapsed time. In reality, the temperature at a given depth will evolve with time and affect the viscosity (Eq. 2). This in turn affects the pore closure rate (Eq. 3). However we will argue below that what matters most is the highest temperature and thus lowest viscosity that the crust experiences.

Application to Mars: For Mars we assume a gravitational acceleration 3.7 m s^{-2} and an upper crust density of 2800 kg m^{-3}. Below are the constants for the four rock types we used in this investigation.

Rock Type [Ref.]	Q (kJ Mol^{-1})	n	A ($\mathrm{MPa}^{-n}\mathrm{s}^{-1}$)
Dry diabase [3]	488	4.7	1.9×10^{2}
Wet diabase [4]	276	3.05	6.12×10^{-2}
Dry anorthite [5]	648	3	$10^{12.7}$
Wet anorthite [5]	356	3	$10^{2.6}$

Assuming a constant temperature, the required temperature for pore closure (which we define as when pores close by a factor of e) decreases as the elapsed time increases (Fig. 1; Eq. 1).

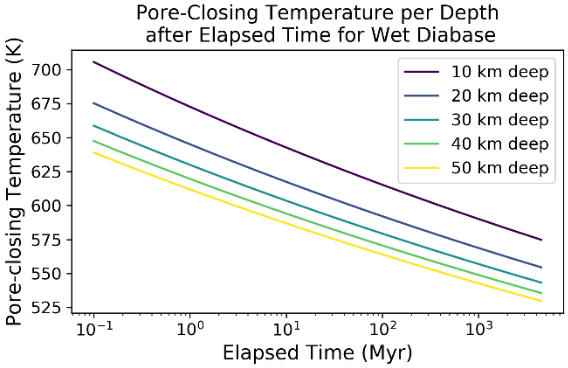

Figure 1: Critical temperature at which pores close after the elapsed time at that depth, for a crust composed of wet diabase.

However, since heat flux—and thus temperature at depth—decreases with time (Fig. 2) [6], the rate of pore closure at a given depth decreases exponentially. The closure of pores is thus controlled primarily by the highest temperature the crust experiences. In Fig. 3 we show the depth at which pores close as a function of (constant) heat flux, assuming a duration of 10 Myr. If the *InSight* experiment detects a crustal interface arising from the removal of porosity, Fig. 3 can be used to determine the maximum heat flux experienced by the crust, depending on the rheology we assume. This, in turn, places constraints on allowable thermal evolution models [6].

Discussion: We have made several simplifying assumptions in this analysis. We assume pores close only viscously and neglect other ways of closing porosity such as cementation or volcanism. We also assume that the entire crust is initially porous, and that no new porosity is generated. Nonetheless, any subsurface region in which porosity is maintained can never have exceeded a given temperature (Fig 1), placing at worst an upper bound on the heat flux. Similarly, a more recent episode of porosity generation would not change the inferred heat flux significantly (Fig 1), although it would change the time to which the heat flux constraint is applied.

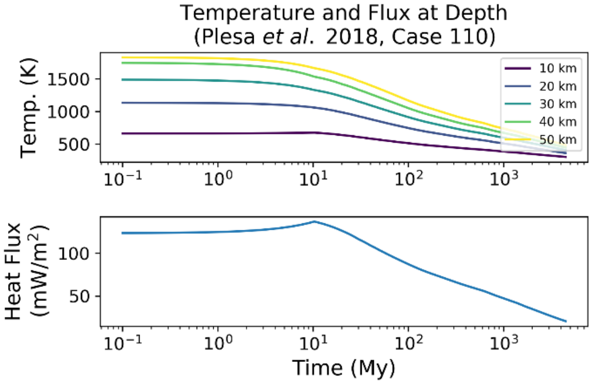

Figure 2: Temperature at depth and heat flux at the *InSight* landing site through time, according to case 110 of the Mars thermal evolution model in [6].

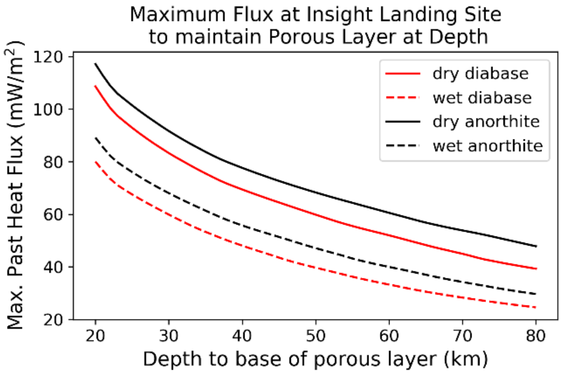

Figure 3: The heat flux at which pores close at each depth. Assumes heating for 10 Myr, with a rapid decrease in temperature thereafter.

References: [1] Wieczorek, M.A. *et al.* (2013) *Science 339*(6120), 671. [2] Besserer, J. *et al.* (2014), *Geophys. Res. Lett.* 41. [3] Mackwell, S.J. *et al.* (1998) *JGR: Solid Earth 103*(B1). [4] Caristan, Y. (1982) *JGR: Solid Earth 87*(B8). [5] Rybacki, E. & G. Dresen (2000) *JGR: Solid Earth 105*(B11). [6] Plesa A.-C. *et al.* (2018) *Geophys. Res. Lett. 45*.