CONSTRAINING CRUSTAL THICKNESS AND HESPERIAN HEAT FLOW ON SOLIS PLANUM, MARS USING DEPTH TO DETACHMENT MAPPING ON BLIND THRUST FAULTS.

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Introduction Wrinkle ridges are prominent structures mapped throughout Mars where they accommodate shortening above thrust faults due to planet-scale loading of the Tharsis rise and other features. Solis Planum contains some of the most distinct and well studied arrays of wrinkle ridges on Mars and is a focus of our work.

Many previous studies have conducted modeling of these wrinkle ridges in order to relate their geometry to underlying blind thrusts [1-8]. Many recent models suggest wrinkle ridges on Solis Planum form above gently curved blind thrusts that flatten in the mid crust. We undertook a more formal analysis of uncertainties in these models [1-8] and sought to determine whether wrinkle ridges form above a single thrust, or are deformed by slip on adjacent (e.g. stacked) faults. This is particularly important for quantitative estimates of the depth at which these thrusts flatten, which has implications for crustal heat flow on the Red Planet in the Hesperian.

Folding: a Proxy for Blind Thrust Geometry As shown in [8], subtle low-relief arches lie between and parallel to wrinkle ridges on Solis Planum. Various efforts at modeling of arches and ridges [4-7] suggest they form above single blind thrusts that progressively flatten with depth. Importantly, these models also predict a nearly flat decollement at shallower levels that may be developed along the base of Hesperian basalt flows in this region, at the top of the weak megaregolith.

Depth to Detachment: Minimum Values Models of single (e.g. unstacked) thrusts yield estimates of minimum depth to detachment. These assume blind faults uplift pairs of arches and ridges and slip is conserved. We used a forward mechanical modeling program called ForcedFold developed by [9] to model the faults beneath the wrinkle ridges and arches. ForcedFold requires user input of observed vertical displacement, fault dip, slope and length of the backlimb, degree of anisotropy of the cover and slip between layers to create topography using rotational listric faulting and a fault tip shear zone based on trishear geometry [10]. From fault dips of 25-40 degrees and appropriate Hesperian cover, thrusts flatten in our models at 12-15 km and 18-22 km. The shallower décollements can be interpreted as corresponding to a weaker layer, perhaps gardened by numerous impact events. The deeper decollement (18-22 km) is interpreted as recording the base of the brittle-ductile transition (BDT) in the Hesperian

Upper Bounds on Crustal Heat Flow We estimate heat flow on Tharsis for the period wrinkle ridges formed there using depth of detachment these faults as marking an isotherm related to the onset of crystal plasticity in gabbroic crust (see [11-13] for terrestrial examples of faulting into the BDT).

Heat flow (Q) is correlative to the thermal gradient ($\delta T/\delta z$) and thermal conductivity (κ) as seen in the following equation:

$$\delta T/\delta z = -Q/\kappa$$

Thermal conductivity is assumed to be 2 W/m-K, based on basaltic composition. We used an isotherm that corresponds to the onset of crystal plasticity in various minerals in gabbro; this ranges from 773 to 873 K [14,15], minus the initial surface temperature, assumed to be 220 K.

The lower limit of depth to detachment at Solis Planum was calculated to be 18 km based on the deeper décollement modeled using ForcedFold, a value that is comparable to [3] or shallower than previously suggested [1,16]. Assuming a similar rheology, we determine an upper bound on heat flux of 61 to 73 mW/m^2, which is higher than Hesperian surface flux estimates of 25 to 50 mW/m^2 [2,17], or mantle estimates of 15 to 30 W/m2 if plate tectonics are invoked [18].

Topographic Offset, Stacked Thrusts and Lower Heat Flow In an effort to determine why our estimates of heat flow are higher than those defined by other methods, [2, 16-18] we undertook a formal comparison between "offset" measured in wrinkle ridges on Solis Planum [8] with axial surface mapping of wrinkle ridges on Solis Planum [3]. This comparison suggests that significant elevation differences (termed offsets) exist from one arch/ridge pair to another in detrended topographic profiles. For examples of decreasing elevation away from the center of Tharsis, this implies that thrusts in this region also uplift adjacent (i.e. towards Tharsis) wrinkle ridges and are thus stacked.

Stacked faults also lead to switching of the sense of offset from one side of the ridge to the other (i.e. the leading edge of paired ridges and arches are uplifted more than their trailing edge). Evidence for this reversal is clearly observed in the wrinkle ridge dataset for Solis Planum (Figure 1). In addition, stacked faulting deforms adjacent ridge-arch pairs such that no undeformed regions lie between them. This can be seen in the profile in the figure below. This hampers our ability to uniquely define the total width of the region uplifted above paired ridges and arches and the depth at which underlying blind thrusts flatten completely into the middle crust on Solis Planum.

Thus, observed width of these folds should be considered a lower bound on the true width of the ridge or arch. Increasing this width changes the depth to which the faults flatten. For example, an increase of 20% of the width of a ridge previously measured as 20 km wide with a fault dip of 40 degrees and an offset of 140 m will yield an increase in depth of faulting from 15.1 km to 16.6 km. This is equivalent to a decrease of heat flow from 73.2 mW/m^2 to 66.6 mW/m^2.

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Figure 1. Stacked faults lead to reversal of offset and the eradication of undeformed regions between arch-ridge pairings.