**LITHOSPHERIC CONTROLS ON THE FORMATION OF VALLES MARINERIS.** F. Scott Anderson and Robert E. Grimm, Department of Geology, Arizona State University, Tempe, AZ 85287-1404.

**Introduction.** Rifting hypotheses for Valles Marineris are based upon the idea that tectonic tensional stresses, most likely associated with the formation of Tharsis, opened the troughs [1]. On Earth, variations in crustal thickness and composition, heat flow, and extension rate are known to control rift style [2-4]. As the first of several quantitative studies of Valles Marineris, we adopt a simple one-dimensional model [4] to test the hypothesis that reasonable values of these parameters alone can account for the general morphology and timing of the rift.

**Model.** The 1D model calculates the change in vertically integrated strength of the lithosphere after a proscribed extensional strain, including time-dependent thermal advection and conduction. The strength of the lithosphere is assumed to be controlled by frictional sliding near the surface and by ductile creep at depth. The latter is sensitive to temperature, composition, and strain rate, whereas the former largely depends only on gravity. Rifts where extension is rapid and vertical advection of heat dominates over conduction are weakened due to uplifted isotherms, resulting in a localized runaway of deformation. Such deformation is characteristic of the "narrow mode" of rifting like the Rio Grande or slightly more complex, anastamosing structures like East Africa. Rifts where extension is slow are strengthened due to the replacement of weak crust by strong mantle at quasi-steady-state temperatures. It is assumed that it is then easier for deformation to move outwards rather than continue in the same location, where the entire process repeats. Such broad lateral sequences of rifts are termed the "wide" mode and are typified by the northern Basin and Range. "Core-complex mode", which is characteristic of parts of the southern Basin and Range, is predicted for narrow rifts in which temperatures are high enough to result in flow of the lower crust [4].

**Application to Mars.** A range of strain rate, heat flux, and crustal thicknesses values were tested. A minimum strain rate may be computed from the minimum estimated strain and the maximum estimated formation interval. A minimum strain rate of $\sim 4\times10^{-18}$ $s^{-1}$ follows from the two-billion-year formation interval of Valles Marineris [1] and a final strain of .25, typical of the strains in individual troughs such as Ius and Tithonium. A minimum extension rate of $\sim 10^{-3}$ cm/yr follows for an extending region 100 km wide. Parameterized convection models for the global thermal evolution of Mars [5] predict that heat flux varied considerably over the period of Chasmata formation (30-100 mW/m$^2$), and indirect mapping of lithospheric thickness around the planet suggests that strong regional variations in heat flux were present [6]. The regional crustal thickness around Valles Marineris is taken to be 40-60 km [7]. The lithosphere was assumed to be composed of a diabase crust [8] overlying a dunite upper mantle [9].

Different combinations of these parameters will uniquely determine the rift style, but the exact mode for Valles Marineris is unclear. The morphology of Valles Marineris is least similar to that of a core complex. Perhaps the most intuitive choice is a narrow rift, due to the great length of the Ius-Melas-Coprates string of canyons. However, the possibility that Valles Marineris is a wide rift should not be ruled out, as two to possibly five incipient parallel troughs are present. These arguments suggest that Valles Marineris is one of three possible cases: (i) A narrow rift, (ii) An incipient wide rift that stopped extending shortly after formation, (iii) A rift that is on the narrow-wide rift boundary. Solutions that exclude the core complex mode alone provide significant constraints without discriminating between wide and narrow rift modes.

**Results.** Figure 1 shows the calculations for Valles Marineris as functions of crustal thickness $H$ and heat flux $Q$ (cf. Fig. 12 in [4]). Positive values for the change in vertically integrated strength, representing wide rifting, are contoured for different values of extension rate $v_x$. The contours may be interpreted as the <u>maximum</u> rifting velocity allowable at a given $Q$ and $H$ to achieve wide rifting. It is important to note that wide rifting cannot occur in this model without a ductile lower crust; therefore wide rifting is easier on Earth than on Mars because of the more felsic composition and greater radioactive heat generation in terrestrial continental crust. However, the slow extension rates likely for Mars partially offset this. The transition to core complex from wide rift is clear where the strength difference changes from positive to negative, but the direct transition from narrow rift is implied from the inflection of the strength difference curve, which, for the case $v_x = 0.01$, is shown as a dashed line in Fig. 1. Similar extensions of other $v_x$ may be inferred.

Rejection of the core complex mode alone for Valles Marineris constrains the heat flux and crustal thickness to lie within $QH < 3000$ mW/m$^2$-km for $v_x = 0.01$ cm/yr; this agrees well with the expected ranges of $Q$ and $H$. For

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higher $v_x$, the direct transition from narrow to core complex mode lies approximately along the axis of the curves and is only slightly more restrictive. Taken together, Q < 80 mW/m$^2$ at the time of rifting. If Valles Marineris is interpreted as an aborted wide rift, then $Q$ lies in the range 30-80 mW/m$^2$ for $v_x = 0.01$ cm/yr; if it is a narrow rift, then $Q < 40$ mW/m$^2$. A higher extension rate of 0.1 cm/yr restricts the wide rift mode to close to 60 mW/m$^2$ and the narrow rift mode to less than this value. Wide rifting at rates characteristic of terrestrial extension, ≥ 1 cm/yr, are completely ruled out.

**Concluding Discussion.** The 1D extension model confirms that narrow rifts can be produced on Mars at the expected range of heat flow and crustal thickness and composition appropriate for the time of canyon formation; in particular, $Q <$ 60-80 mW/m$^2$. However, wide rifts are more difficult to initiate, and are restricted to extension rates < 0.1 cm/yr.

This work provides the foundation to address three principal outstanding questions for Valles Marineris: (1) Why are the canyons so deep? (2) What was the nature of lithospheric weakness (aquifers, pre-existing structures) that localized extension within a presumably more homogeneous regional stress field? (3) Did the rift propagate with time, as suggested by the inability of the best stress models to extend at both ends of the canyon system simultaneously [10]? Finite-element modeling in both section and plan view will provide sufficient flexibility to answer these questions.

**References** [1] B.K. Luchitta et al, in *Mars* (eds. H. Kieffer, B. Jakosky, C. Snyder, and M. Matthews), Ch. 14, Univ. of Ariz. Press, 1992; [2] N. Kusznir and R. Park, *Spec. Pub. Geol. Soc. Lond., 28*, 35, 1987; [3] P. England, *JGR, 88*, 1145, 1983; [4] W.R. Buck, *JGR, 96*, 20161, 1991; [5] G. Schubert et al, in *Mars* (op. cit), Ch 5; [6] S. Solomon and J. Head, *JGR 95*, 11073, 1990; [7] G. Balmino et al., *JGR, 87*, 9735, 1982; [8] Y. Caristan, *JGR, 87*, 6781, 1982; [9] P. Chopra and M. Paterson, *Tectonophys., 78*, 543, 1981; [10] W. Banerdt et al., *JGR, 87*, 9723, 1982.

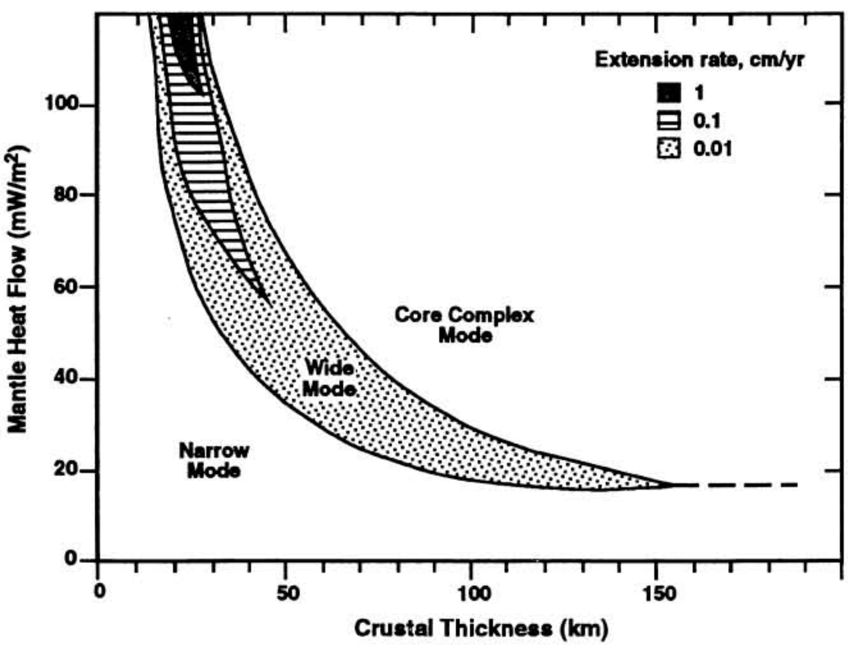


Figure 1. Rift mode on Mars. Expected range of heat flow (30-100 mW/m$^2$) and crustal thickness (40-60 km) agree with either narrow or wide mode but not core complex. Wide rifting further requires $v_x < 0.1$ cm/yr.