**THE FORMATION OF VALLES MARINERIS, MARS.** J. C. Andrews-Hanna, Department of Geophysics, Colorado School of Mines, Golden, CO, jcahanna@mines.edu.

Introduction: Valles Marineris is the most prominent tectonic feature on Mars, consisting of troughs up to 2000 km in length, 200 km in width, and 10 km in depth. A scenario for trough formation is here proposed that is consistent with the geological and geophysical evidence, and predicts *a priori* the observed trough depths. The proposed mechanism entails a combination of Tharsis loading over the crustal dichotomy boundary, a narrow band flexural tensile stresses along the buried boundary, magmatic weakening of the lithosphere, vertical subsidence of super-isostatic crust, and sedimentary loading. The mechanism is outlined below in a series of sequential stages.

Stage 1: Impact origin for the martian dichotomy. The first event of direct relevance to the formation of Valles Marineris is the origin of the martian dichotomy. Recent work supports an impact origin for the dichotomy on the basis of the elliptical shape of the northern lowlands, in resemblance to other giant impact basins [1]. Regardless of the mechanism, the formation of the crustal dichotomy resulted in a step function in topography and crustal thickness across a boundary that nearly bisects Tharsis (Figure 1). Significantly, Valles Marineris is south of and semi-parallel to the buried boundary.
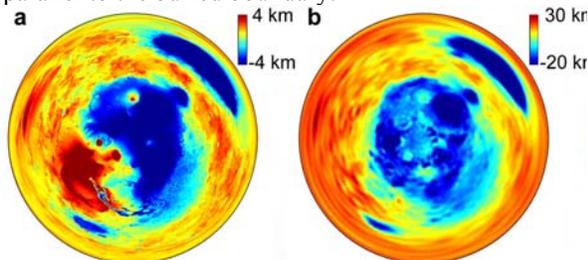
Figure 1. Present-day topography and isostatic roots of Mars in a polar projection centered around the center of the lowlands, revealing their elliptical shape.

Stage 2a: Tharsis volcanism and localized flexural stresses. Long-lived volcanism concentrated in the Tharsis region resulted in the construction of a volcanic rise covering ~15% of the surface of Mars. The emplacement of this volcanic load straddling the pre-existing step of the dichotomy boundary resulted in an abrupt change in the thickness of the load across the boundary. This differential loading resulted in differential flexure across the buried boundary, generating strong tensile stresses in the upper half of the lithosphere south of the location of the buried boundary (Figure 2a) [2]. These focused flexural stresses account for the formation of the troughs immediately south of and semi-parallel to the buried dichotomy boundary

beneath Tharsis. While an axisymmetric load predicts an extensional stress belt extending across the entirety of Tharsis, models tuned to fit the present-day crustal thickness predict a rotation of the extensional stress vectors by ~90° at the western end of Valles Marineris as a result of the loading stresses associated with the Tharsis Montes. This is consistent with the location of the complex Noctis Labyrinthus chasmata.
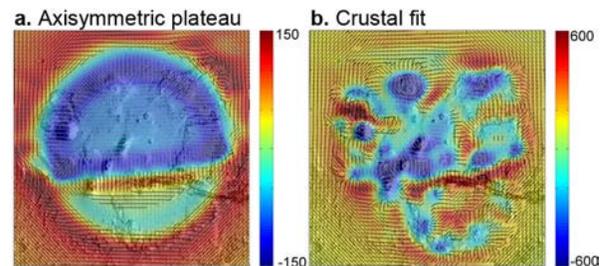
Figure 2a. Predicted flexural stresses (red=extension) and stress vectors (black lines=extension) from models of volcanic loading over the buried dichotomy boundary for an axisymmetric load (left) and a load that matches the present-day crustal thickness (right).

Stage 2b: Flexural support of super-isostatic crust within Tharsis. As a result of the regional flexural support of Tharsis, the thickened crust of the rise is held above its isostatic level. The isostatic anomalies, representing the difference between the observed topography and that which would result if the crust were in a state of isostasy, reveal that much of the rise sits well in excess of 1 km above its isostatic level, with a mean isostatic anomaly of ~800 m (Figure 2b). This crust would subside to its isostatic level were it not supported by the elastic strength of the lithosphere.
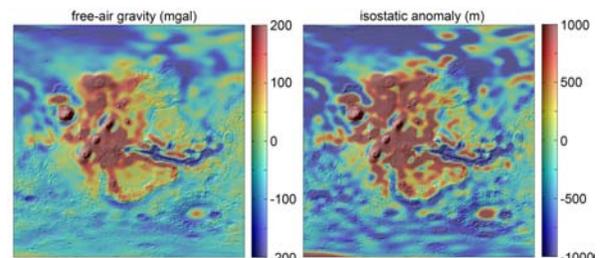
Figure 2b. Free-air gravity anomalies (left) and isostatic anomalies (right) within Tharsis.
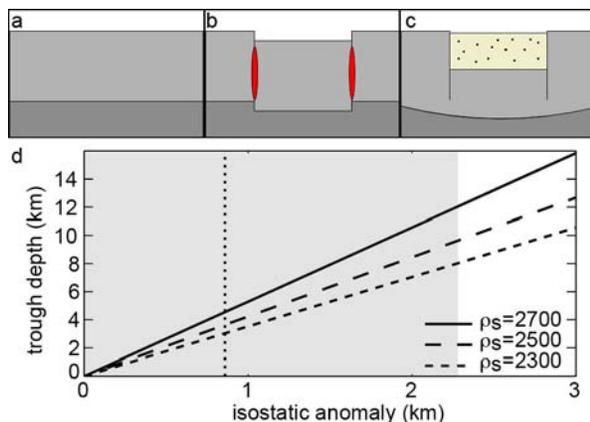
Stage 3: Magmatic intrusion and isostatic subsidence. There is widespread evidence throughout Tharsis for intrusive magmatism, resulting in small-scale collapse features along linear trends parallel to the present-day troughs (Figure 3). These magmatic intrusions would have released the flexural stresses within the lithosphere. Intrusions would initially be limited to the tensile upper portion of the lithosphere, but release of

the stresses in the upper lithosphere would cause the lower portions of the lithosphere to transition into extension as well. Ultimately, the magma bodies would penetrate the full vertical extent of the lithosphere, and elongate on trends perpendicular to the σ_3 direction, and thus parallel to the buried dichotomy boundary. Two parallel magma bodies or dikes would remove the lateral flexural support of the intervening block of super-isostatic crust within Tharsis. When this block achieved some critical length, it could no longer be supported by the connections at its ends to the adjacent lithosphere. The unsupported lithospheric blocks would then subside to their isostatic level ~1 km below the surrounding plateau surface (Figure 4b).
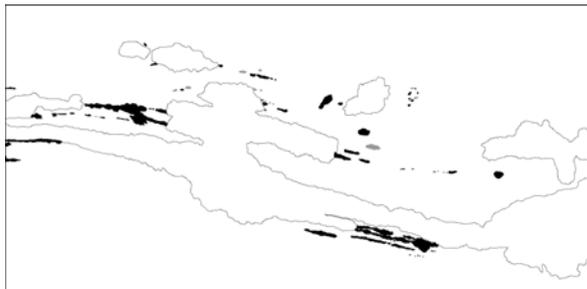
Figure 3. Distribution of collapse features (black) and surface sags (gray) above magma chambers.

Stage 4: Sedimentary loading and further subsidence. Formation of the proto-troughs through isostatic subsidence would generate hydrological sinks into which groundwater would inexorably flow [3]. The resulting aqueous processes would lead to sedimentary infilling of the forming troughs with evaporite-cemented clastic materials, generating the interior layered deposits. The addition of this sedimen-


Figure 4. Proposed sequence of (a) initial super-isostatic crust (light gray) overlying mantle (dark gray), (b) magmatic intrusion and trough subsidence, and (c) sedimentary loading and further subsidence. (d) Predicted trough depth as a function of the isostatic anomaly for a sediment density of 2700 kg/m^3. Mean and standard deviation isostatic anomaly in Tharsis are indicated by the dotted line and gray region.

-tary material to the trough floors would increase the overburden, driving further subsidence (Figure 4c). As the trough floors subside, the relief at the Moho would be smoothed by viscous lower crustal flow. The magnitude of the final subsidence would be dictated by the sediment density and the initial super-isostatic state of the plateau. For the observed super-isostasy of Tharsis, subsidence of the trough floors to levels as much as 12 km below the surrounding plateau is predicted. This mechanism predicts syn-tectonic deposition of the ILD's, in agreement with the observation of extensive faulting and folding of the deposits [4, 5].

Stage 5: Erosion of the sedimentary trough fill. The formation of the troughs by the above sequence would end with each trough being filled to near the top with sedimentary deposits, in agreement with the observed thicknesses of the ILDs in some troughs (Figure 5). The later termination of the hydrological cycle [6] left the trough-filling deposits susceptible to aeolian deflation, ultimately leaving behind isolated mounds of remnant deposits.
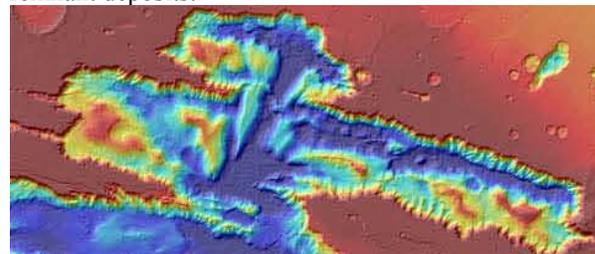
Figure 5. MOLA topography of ILD's partially filling Ophir and Candor chasmata to near the plateau height.

Conclusions. The above sequence of events would result in the formation of partially sediment-filled tectonic troughs up to 12 km in depth through a combination of volcanic loading, flexure, horizontal extension, sedimentary loading, and vertical subsidence. While this mechanism requires a combination of conditions unique to Tharsis on Mars, aspects of the mechanism bear similarity to tectonism on Earth. The processes of magmatic weakening of the lithosphere, sedimentary loading, and isostatic subsidence play key roles in rift valley formation on the Earth.

References.
[1] Andrews-Hanna J. C., et al. (2008) *Nature 453*, 1212-1215. [2] Andrews-Hanna J. C. (2009) *LPSC 40*, Abstract 1094. [3] Murchie S. L., et al. (2009) *JGR 114,* E00D05, doi:10.1029/2009JE003343. [4] Fueten F., et al. (2008) *JGR 113*, E10008, doi:10.1029/ 2007JE003053. [5] Okubo C. H. (2010) *Icarus 207*, 210-225. [6] Andrews-Hanna J. C. and Lewis K. W. (2010) *JGR*, doi:10.1029/2010JE003709, in press.