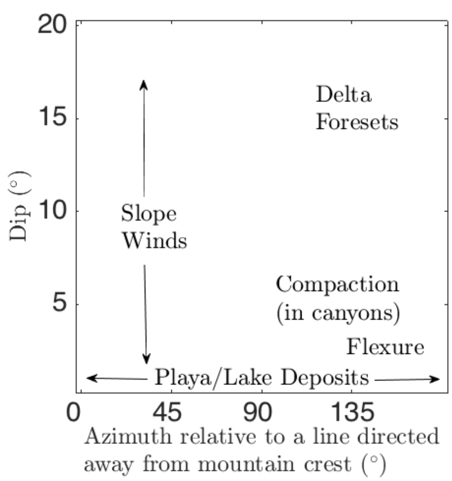
ORIGIN OF SEDIMENTARY-ROCK MOUNTAINS ON MARS CONSTRAINED BY LAYER-ORIENTATION DATA.

Jonathan Sneed[1], David P. Mayer[1], Kevin W. Lewis[2], Edwin S. Kite[1] (kite@uchicago.edu).
[1]University of Chicago, [2]Johns Hopkins University.

Summary: The tallest sedimentary-rock mountains on Mars sit within Valles Marineris. We use 200 HiRISE DTM layer orientation measurements to show that layers within the mountains systematically dip away from the mountain crest-lines. These data are not consistent with with tilting of initially horizontal sediments by compaction, flexure, or crustal-flow. The data are also not consistent with delta-foreset deposition (with sediment sourced from canyon walls). The data are consistent with: upwarping of the mountains by linear canyon-centered diapirs, with selective dissolution/dehydration of outer layers during mountain formation, or with enhanced erosion by slope winds.

<u>Predictions:</u>



<u>Observations:</u>

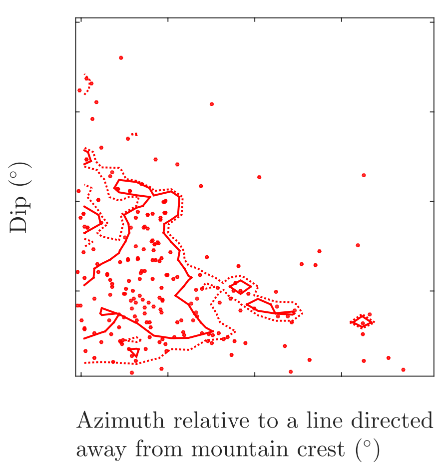


Fig. 1. Summary of results, for measurements above the interpolated basal surface of the mountains. Dots are individual measurements with ≤2° pole error. Inner and outer contours enclose 50% and 68% of measurements.

Background: Malin and Edgett [1] divided Mars sedimentary rocks into three classes of unit. The youngest, dark-toned "thin mesa" units, and unconformably drape all other rocks. The surfaces defined by interpolating "thin mesa" outliers are similar to modern mound topography. Therefore, sedimentary-rock deposition continued after mound shapes were defined. [2] used a basic physical model of wind erosion to interpret the outward tilts of layers at Mt. Sharp. They proposed that Mt. Sharp grew by draping, with erosion by slope-winds defining a moat around the growing mound (a syndepositional moat). Alternatively, [3] and [4] propose the mountains contain lacustrine/playa sediments, in which case layer tilts must correspond to postdepositional tilting mechanisms such as compaction or flexure. Using layer-tilt data obtained from HiRISE DTMs, we set out to test the contrasting predictions of these mountain-formation models.

Methods: Bedding plane traces were carried out by visual inspection using 1m-pixel orthorectified digital elevation models and paired HiRISE images in Ceti Mensa, Nia Mensa, Juventae Mensa, Coprates Mensa, and Melas Mensa, plus Mt. Sharp, according to the methods used in Ref. [11]. Our DEM production process used the Ames Stereo Pipeline; comparison of our DEMs to PDS-released DEMs showed ≤0.2° relative tilt. Strike and dip were calculated for the r^2 best fit planar interpolation of each bed trace. Error was calculated using the methed of [11], with samples rejected if pole error was >2°. In addition to the stereo DEMs, digital models of each sedimentary mound were built from existing MOLA data at ~400m per pixel. Mound boundaries, and the crest lines of elongate mounds, were drawn by visual inspection of THEMIS mosaics. A mound basal surface was defined using cubic polynomial interpolation within mound edges. Elevation above mountain base is calculated as the difference between measured elevation and the basal surface.

How we know that our measurements are not biased downslope: Errors in tracing a layer on a slope on an orthorectified image will produce a downslope bias in plane-fits to the trace using the corresponding DEM. A decisive test for this bias is to compare our measurements using a DEM derived from a HiRISE stereopair to those made on a simultaneously-acquired CTX stereopair. If downslope bias affects the HiRISE layer orientations, then the same layers traced on CTX will suffer a bias that is proportionally more severe. For the region covered by the ESP_013540_1745/ESP_012907_1745 stereopair (where layers typically dip at right angles to the local downslope), we found that CTX measurements are similar to HiRISE measurements (Fig. 2). We did not find a large systematic bias downslope in the CTX traces relative to the HiRISE traces. This shows that the downslope bias of HiRISE layer-orientation data is small.

If the layers are initially horizontal, and dips are produced by downslope slumping in a near-surface mobile layer, then we would see larger dips for traces with a smaller range of absolute elevations. We found the opposite trend, excluding this potential source of error.

We also found consistency between measurements by workers using the same procedure, both within our lab and between labs. For example, at Gale, outward dips have been independently confirmed by [2,4,5,6].

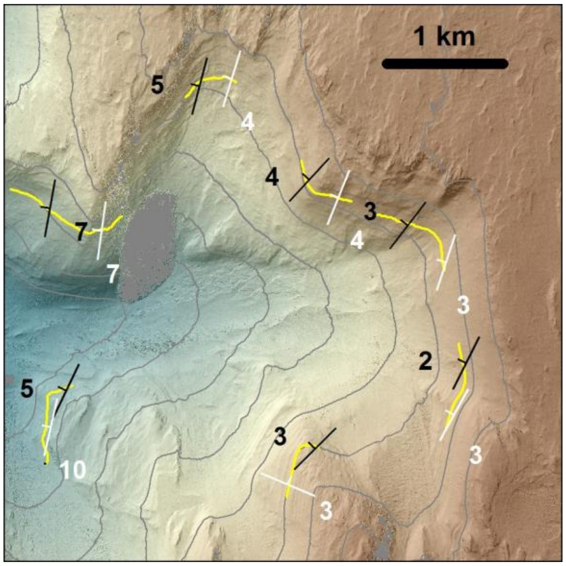


Fig. 2. Examples of layers (yellow), showing similar dips whether traced on CTX DTMs (white) or HiRISE DTMs (black). Contour interval 100m, red is high, backdrop is HIRISE DTM shaded relief.

Results: Bedding planes usually dip away from mound centerlines (Fig. 1). For layers above the mountain base, the dip azimuth of measured beds falls within 90° of the vector directly away from the nearest mound crest in 90% of measured beds, and within 45° in 64%. Bedding plane angles ranged from ~0-18 ° from the horizontal, with a tendency towards steeper angles as elevation increases. Systematic outward dips have also been reported for Hebes Mensa [7] and Ganges Mensa [8].

Independent evidence from landslides and unconformities: R.P. Sharp noted [9] that gravity-slide deposits, when stratigraphically encapsulated, reflect the location of paleo-highs on unconformity surfaces. Landslides in Ceti Mensa [10], around Juventae Mensa, at Mt. Sharp, and possibly at Melas Mensa, are directed away from the mountain crest and stratigraphically overlain by sedimentary rocks. This shows that sedimentary-rock deposition continued after the moats were defined.

Fitting quadratic surfaces to previously-mapped [7,13-16] large unconformities at W Candor, Ophir and Gale shows that most of the unconformity surfaces, regardless of who mapped them, are domes. Best-fit paleo-highs are located close to modern topographic highs. This is a third independent line of evidence for syndepositional moats.

Implications: Because Valles Marineris graben have flat, noncompactible floors (away from sediment mounds), sediment compaction would produce flat or inward dips. However, we see outward dips in the Valles Marineris mountains, ruling out differential compaction as the cause of the tilts. The data are consistent with mound formation by draping interspersed with moat-deepening (i.e., a syndepositional moat).

Our data span a range of elevations, from the base of the mountains up to the summits. At the conference, we will discuss the relationship between layer orientations and stratigraphic elevation. Fig. 3 shows that the trend for layers to dip away from the mountain crest is more pronounced at higher elevations above ther interpolated basal surface, although it remains significant even for beds at <0.5 km. We will also discuss the relationship between layer orientations and presence/absence of aqueous-mineral detections.

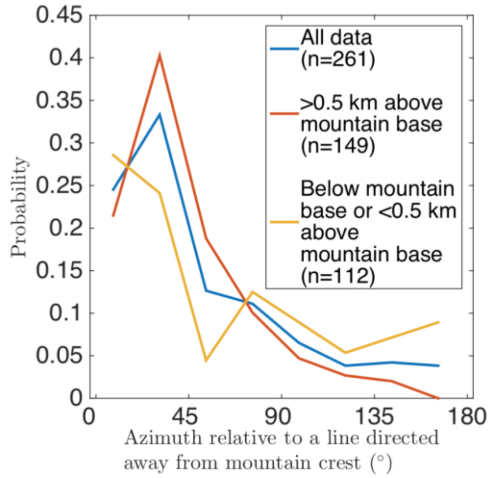


Fig. 3. Distribution of layer orientations relative to elevation above mountain base. Includes 61 data from [2].

References: [1] Malin & Edgett (2000) *Science* [2] Kite et al. (2013) *Geology*, 41(5), 543-546. [3] Murchie et al. (2009) *J. Geophys. Res.* 114 E00D05. [4] Andrews-Hanna (2012) *J. Geophys. Res.* 117, E06002. [5] Lewis & Aharonson (2014) *J. Geophys. Res.* 119, 1432-1457. [6] Fraeman et al. (2013) *Geology*, 41(10), 1103-1106. [7] Le Deit et al. (2013) *J. Geophys. Res*. 118, 2439-2473. [8] Stack et al. (2013) *J. Geophys. Res*. 118(6), 1323-1349. [9] Timmins et al. (2014) *45th LPSC.* [10] Hore (2014), MSc Thesis, Brock University. [11] Sharp (1940), *Am. J. Sci.* vol. 238. [12] C. Okubo (2014), USGS Scientific Investigations Map 3309. [13] Anderson & Bell (2010) *Mars Journal* 4, 76-128. [14] Thomson et al. (2011) *Icarus* 214, 413-432. [15] Lucchita (2015) *46th LPSC.* [16] Wendt (2011) *Icarus* 213, 86-103.