ANALOG MODELING OF NORMAL FAULT GROWTH ON MARS. D. Y. Wyrick[1], A. P. Morris[1], and D. A. Ferrill[1], [1]Department of Earth, Material, and Planetary Sciences, Southwest Research Institute® (6220 Culebra Rd., San Antonio, TX, 78238-5166, USA; dwyrick@swri.org).

Introduction: Normal faults evolve from systems of unconnected fault ruptures, to poorly connected networks formed by linkage of propagating faults, to strongly interconnected fault networks with isolated fault blocks. This evolution tends to progress with increasing duration or magnitude of extension [1, 2, 3]. Individual faults develop sawtooth along-strike displacement profiles, which are attributed to growth by fault linkage (e.g., [4, 5, 6, 7, 8]). The relationship between maximum displacement and tracelength (Dmax/L) of faults has been studied for at least two decades [9], in particular the extent to which this relationship represents self-similar fault development or not (e.g., [5, 10, 11, 12, 13]), and whether it represents some fundamental characteristic of the faulted medium, displacement accumulation, or fault linkage processes (e.g., [10, 13, 14]). There is, however, a distinction between displacement versus length relationships for individual faults, fault arrays consisting of multiple cooperating faults, and individual faults within a fault array (e.g., [5, 6]), and there is a growing body of evidence that fault ruptures do not grow by self-similar increments, but evolve to higher maximum displacement to length ratios with successive slip events [15, 16, 17].

Displacement versus length relationships of faults on Earth and other planets have been used to describe and interpret the evolution of faults and fault systems [6, 4, 18, 19, 20, 21], and to infer differences in mechanical stratigraphy [22]. We describe physical analog modeling and analyses of data from Martian fault systems to support the interpretation of fault system development on Mars. We conclude that simple faults (single throw maximum) do not grow in a self similar manner, and that compound faults (multiple throw maxima) develop in a stepwise pattern in Dmax/L space.

Physical analog modeling: We use a physical analog model to simulate normal faulting in response to distributed extension in a brittle layer over a horizontal detachment surface. The mechanically brittle layer was simulated by a 2 cm thick clay layer that behaves as a time-independent material at the strain rates used in this experiment and is interpreted to be scaleable to crustal processes [23, 24]. Dynamic Structured Light (DSL) imaging was used in conjunction with the photographic images to produce a digital terrain model of the surface [25]. For these models, photos and DSL were captured at 5 mm displacement increments. A total of 100 mm of displacement was applied to the model (~25% model extension).

Footwall (upthrown) and hanging wall (downthrown) fault traces were mapped and elevation data were extracted from the DSL data. Fault displacements were measured in terms of throw (vertical component of fault displacement) because this is directly extractable from the elevation data and requires no interpretation or secondary measurement of fault dip.

Increases in throw and length generate different pathways through maximum throw (Dmax) versus trace length (L) space. Throw accumulation is relatively slow and is separate from rapid length accumulation events. Tracing simple faults (later fault segments) in Dmax versus L space illustrates the stepwise evolution of a compound fault.

There is a strong positive correlation between fault trace length and the number of segments incorporated into a fault. The more evolved fault population (18% model extension) contains faults with greater maximum throw, trace length, and number of incorporated segments.

Martian fault analyses: We analyzed Martian normal fault systems to explore these natural systems for patterns of throw versus trace length, and to assess whether they match observations from analog modeling, suggesting segment linkage processes similar to or different from those observed in our analog models. Normal fault systems on the flank of Alba Patera were chosen for this investigation because they are well imaged by all generations of data coverage, and because they contain fault systems that have a range of developmental characteristics. Compared with other faulted regions of Mars, those surrounding Alba Patera have relatively uncomplicated fault patterns; they have only one or two dominant fault strike directions, and the tectonic setting is primarily extensional [26, 27, 28, 29]. We focused this investigation on fault systems on the northwestern flank of Alba Patera that includes part of the Alba Patera Fossae. The limited post-faulting modification by weathering and erosion justifies the approximation that displacement of the topographic surface represents the vertical component (throw) of displacement across the fault. We recognize the likelihood of surface processes on Mars having modified the footwall and hanging wall geometries of faults, and this would probably decrease estimates of maximum throw, displacing our Mars data toward lower Dmax/L ratios than our analog model results.

Footwall and hanging wall cutoff traces of more than 300 faults were interpreted using Viking imagery and ArcGIS software. Elevations for interpreted points were obtained from gridded MOLA data. Throw versus along-strike trace length plots were constructed for each interpreted fault. Drawing upon our experience with physical analog models, each throw profile was then analyzed to determine the number of throw maxima and hence the number of individual segments incorporated into the fault.

The number of segments incorporated into compound faults is positively correlated with fault trace length, similar to results from analysis of faults in the analog model. In a plot of Dmax/L, compound faults are distributed parallel to loci of constant Dmax/L ratio, bounded by Dmax/L = 2×10^{-3} to 2×10^{-1} and spanning two and a half orders of magnitude in terms of trace length.

Discussion: *Fault frequency.* Observations of the analog modeling presented here, as well as results of other extensional physical analog models (e.g., [3, 23]) indicate that simple faults first appear at relatively small extension values, in this study at 6% to 8% model extension. Initial appearance is followed by rapid proliferation of faults over model extensions up to about 12 or 13% and stabilization over the remainder of the model deformation up to extensions of ~30%.

Patterns of Dmax/L evolution. Faults in this modeling study have two modes of growth, first by throw accumulation accompanied by some length increase at no more than one order of magnitude greater than the rate of throw increase, and second by linking, which causes length increase to outpace throw increase by two orders of magnitude or more.

Controls on Dmax/L evolution. Dmax/L ratios for simple faults are likely controlled by the mechanical properties of the faulted material under the conditions of deformation, and such a fault developing in isolation would likely follow a steep path in Dmax/L space (i.e., dominated by throw accumulation). However, length accumulation of most faults within a population is dominated by linkage processes, and is thus a function of the number of linkage opportunities available.

Our physical analog data indicate that faults evolve through Dmax versus L space in a stepwise fashion corresponding to periods of throw accumulation (steep slopes) and linkage (shallow slopes).

The number of segments incorporated into compound faults is positively correlated with the fault trace length. This suggests that the apparent self-similar evolution of Dmax/L is in part due to fault linkage. Thus, with successive slip events, faults are likely to link rather than accumulate throw without linking with other faults.

Dmax/L on Mars. Recognition of throw maxima within the throw profiles of Martian faults from Alba Patera indicates that these faults evolved by fault segment linkage. The strong positive correlation between number of linked segments and fault trace length suggests that segment linkage is the principal determinant of fault length as it is in the case of normal faults developed in analog models. We infer that Martian faults develop by two complementary but distinct processes, throw accumulation and segment linkage.

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