GEOMETRY AND EVOLUTION OF SEGMENTED NORMAL FAULT SYSTEMS ON MARS. A. M. McMillin and S. A. Kattenhorn, Department of Geological Sciences, University of Idaho, Moscow, ID 83844-3022, mcmi7099@vandals.uidaho.edu, simkat@uidaho.edu

Introduction: Relay zones represent an important stage of fault system evolution in normal faults [3]. By analyzing the geometric features characteristic of relay zones in various stages of linkage development, we can infer whether or not a relay zone is linked based on its geometry [9]. Fault systems in three different areas of the Alba Patera region (fig 1) and two areas of the Tempe Terra region were mapped using images from the High Resolution Stereo Camera (HRSC) and analyzed using ArcGIS software.

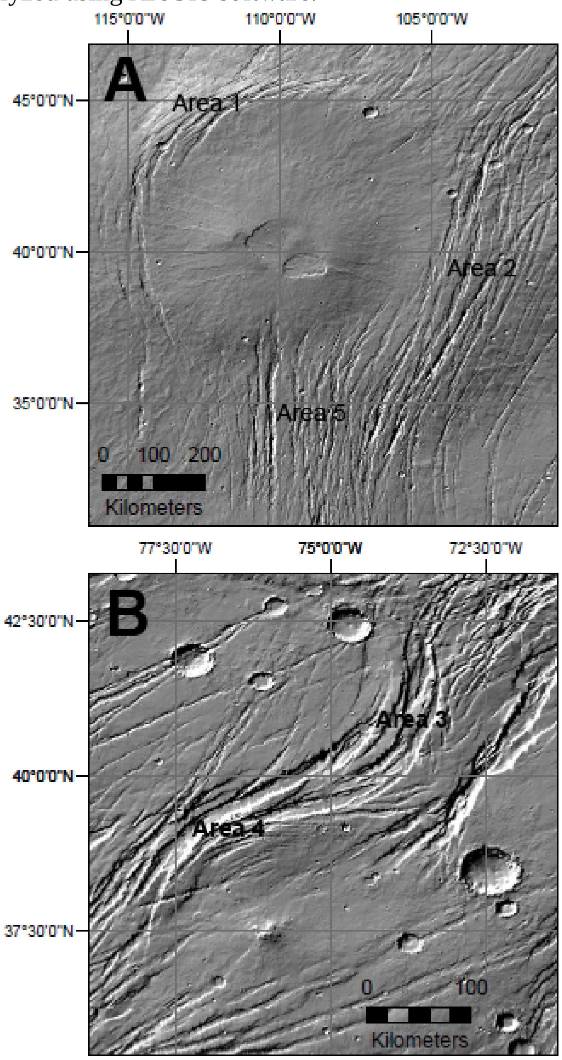

Figure 1. Study area locations indicated on MOLA hillshade imagery. A) Alba Patera; B) Tempe Terra

Between 20 and 35 systems of segmented normal faults were mapped in each of these areas, and 150 relay zones were identified for use in our analysis on the basis of exposure and the relative absence of other structural features not thought to be directly related to relay zone evolution.

Alba Patera is a plateau that developed as a result of shield volcanism in the Noachian and Hesperian [7, 8]. Five historic stages of deformation have been documented in Alba Patera [1]. Concentric normal faults bound the plateau to the northwest. Fault systems in this region are highly variable in total length, ranging from 50 to 150km long. Relay ramps are well exposed and often free of cross-cutting features, making them ideal for gathering geometric information. Linear north-south trending fault systems extend directly to the south of the plateau. Graben here are up to 250km long and the maximum throw is about 2km. Trend variations of up to 10 degrees and en echelon geometry is typical of the northernmost segments of these systems. East of the volcanic center, fault systems have an average trend of 009° and are typically 50 to 100km long, though some are as long as 150km.

The Tempe Terra rift system is located northeast of the Tharsis Region and interpreted as the result of Tharsis dike swarms [10]. Fault systems in the northeast area of Tempe Terra form the Tempe Fossae rift, which has been presented as a possible Martian analog for rift systems in East Africa based on the general change in fault length from south to north along the entire system [6]. Faults in the southwestern-most area are up to 180km long and have an average trend of 043°, and faults directly northeast of these are 80 to 120km long and nonlinear. Many segments in both areas show en echelon geometry.

Fault Geometry: Fault scarps and relay zone surfaces (relay ramps) were mapped as separate polygon units in ArcGIS so that spatial data for specific features including contour lines, DEM data, slope rasters, and hillshade images could be isolated and overlaid. While the resolution of HRSC DEMs is not high enough to provide detailed information about features at fault tips, it can still give us general information about relay zone features such as relay ramp tilt (toward the front or rear segment) and the amount of throw accomodated by the relay zone [5], which can provide insights into how these features relate to segment linkage.

Relay zone geometry is quantified in terms of overlap and spacing between the fault segments [3], throw across the relay zone, and the tilt direction of the relay ramp at the surface. Segment overlap is given as a measure of distance along the strike of the fault system and represented as a percentage of total segment length and as ratios relative to the horizontal spacing between the segments and the total throw accommodated by the relay zone at the surface. Additionally, ten fault systems with well-exposed scarps and relay zones were selected to analyze the effect of position along the fault system on segment evolution. This also allows for the creation of precise throw profiles for the entire length of the fault system inclusive of the throw accommodated by the relay zone.

Relay zones between fault segments were divided into four primary categories: breached, unbreached, possibly breached, and possibly unbreached. Breached and possibly breached relay zones were further divided based on the location of the breach (at the upper ramp, the lower ramp, or both). The probable presence of a monocline across the relay ramp surface was also noted in several cases.

Relay zone geometry was then compared to the nature of the linkage between the segments to determine what geometric features appear to have the greatest influence on or relationship to segment evolution. Initial results suggest that the overlap to spacing ratio does not correlate to segment evolution. However, work on terrestrial rifts [3,9] suggests that the relationship is highly dependent on the amount of throw across the relay zone, and further investigation will determine if this holds true for Martian faults.

Monoclines and Fault Evolution: Monoclines have been documented in the concentric fault systems in the northwest part of Alba Patera and interpreted as evidence for the upward propagation of faults that initiated at depth [12], consistent with terrestrial normal faults in basalt terranes [4]. En echelon segment geometry observed in the other study areas at Alba Patera further suggests this mechanism for fault growth. Though en echelon geometry was also observed at Tempe Terra, the presence of cross-cutting features presents an ambiguity as to the origin of this geometry.

An important observation has been the possible occurrence of monoclines developing across some of the relay zones. These features were identified as monoclines on the basis of vertical relief observed on DEMs and shadows on the aerial imagery that suggest vertical relief but show no apparent fault scarp (fig 2).

The presence of monoclines carries implications for the processes of fault development and relay zone evolution. Monoclines are interpreted to represent a specific stage of linkage evolution, in which fault segments are linked in the subsurface. The occurrence of monoclines across relay zones has been documented in terrestrial fault systems, such as the Big S Monocline on the Hat Creek Fault [11]. Furthermore, monoclines suggest that faults initiate in the subsurface and propagate upward. Subsurface linkage is an important aspect of the evolution of terrestrial segmented normal faults [2], and observing indications of it in Martian faults will help us understand how these fault systems and linkages evolve.

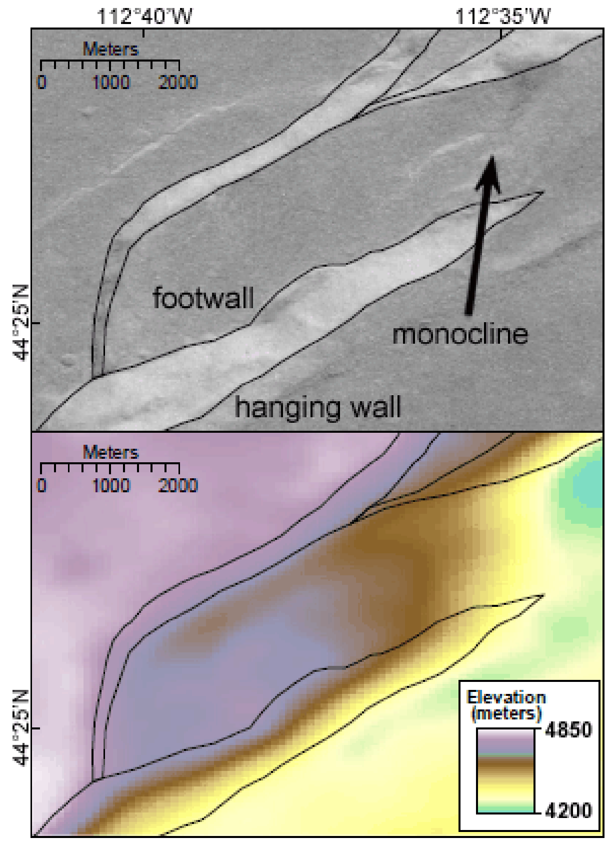

Figure 2. HRSC aerial photo and DEM imagery of a monocline across the lower part of a relay zone in Alba Patera. Faults are dipping to the southeast, and the upper part of the relay zone has been breached at the surface. Relay ramp tilt is toward the rear segment.

References: [1] Anderson R.C. et al. (2004) *Icarus, 171*, 31-38. [2] Childs et al. (1995) *J. Geol. Soc., London*, *152*, 535-549. [3] Crider J. G. and Pollard D. D. (1998) *J. Geophys. Res., 103*, 24,373–24,391. [4] Grant J. V. and Kattenhorn S. A. (2004) *J. Struct. Geol., 26*, 537–557. [5] Hauber et al. (2007) *7th Intl. Conf. on Mars*, Abstract #3110 [6] Hauber E. and Kronberg P. (2001), *J Geophys. Res., 106*, 20,587-20,602. [7] McGovern, P.J. et al. (2001) *J. Geophys. Res., 106*, 23,769-23,809. [8] Polit et al. (2009) *J. Struct. Geol., 31*, 662-673. [9] Soliva R. and Benedicto A. (2004) *J. Struct. Geol., 26*, 2251-2267. [10] Tanaka et al. (1991) *J. Geophys. Res., 96*, 15,617-15,633 [11] Walker, E.W. (2008) *Master's thesis, University of Idaho*, 224p. [12] Wyrick D.Y. et al. (2011) *Icarus, 212*, 559-567.