THE CANYONLANDS GRABENS REVISITED, WITH A NEW INTERPRETATION OF GRABEN GEOMETRY. Richard A. Schultz and Jason M. Moore, Geomechanics-Rock Fracture Group, Department of Geological Sciences, Mackay School of Mines, University of Nevada, Reno, NV 89557-0138 (http://unr.edu/homepage/schultz; schultz@mines.unr.edu).

Summary.
The relative scale between faults and faulted-layer thickness is critical to the mechanical behavior of faults and fault populations on any planetary body. Due to their fresh, relatively uneroded morphology and simple structural setting, the terrestrial Canyonlands grabens provide a unique opportunity to critically investigate the geometry, growth, interaction, and scaling relationships of normal faults. Symmetrical models have traditionally been used to describe these grabens, but field observations of stratigraphic offsets require asymmetric graben cross-sectional geometry. Topographic profiles reveal differential stratigraphic offsets, graben floor-tilts, and possible roll-over anticlines as well as footwall uplifts. Relationships between the asymmetric graben geometry and brittle-layer thickness are currently being investigated.

Introduction and Background.
The grabens in Canyonlands Country [1] are located in the central part of the Colorado Plateau, southeastern Utah, and in the northwestern part of the Paradox Basin [2,3]. The grabens are developed in Paleozoic rocks dipping gently (≈4°) to the west, between the west limb of the Monument uplift and the more steeply dipping east limbs of valley anticlines exposed along the Colorado River and other major canyons in the region [4-6]. The canyons near the grabens were cut by the Colorado and Green Rivers, resulting in localized unloading of the strata overlying the Pennsylvanian Paradox Member of the Upper Hermosa Formation [7], during Pleistocene to Holocene time [8,9]. The unloading apparently resulted in vertical movement of Paradox evaporites to form valley anticlines [e.g., 4]. Lateral flow of Paradox gypsum and salt is thought to have formed the grabens in subjacent rocks (Upper Hermosa Formation, Rco Formation, Cedar Mesa Member of the Cutler Formation) [e.g., 10,11]. Present-day extension due to salt flow is suggested by deformation of Quaternary sediments to the north in Salt Valley [12], topple failures of vegetated slabs in Canyonlands graben walls [13], and swallow holes [14] or cracks along many grabens that are continuing to widen today.

Methods and Results.
A combination of new field work and extraction of precision microtopography from stereo air photos, using a Kern PG-2 plotter, provides a new look at these classic grabens. Our field work reveals first-order characteristics of grabens in Canyonlands that were not identified in previous investigations. These surprising findings include:

1. Significant differences in stratigraphic offset across most grabens, much greater than that found by Trudgill and Cartwright [13]. We identified several (≈10) examples where displacements on one wall were less than 80% or so of those on the opposite wall. These examples occur in the simpler, “outer domain” [11] in addition to the more complex “inner domain.”

2. Identification of a possible rollover anticline in the hangingwall of the Devils Lane graben suggesting flexure of the hangingwall due to translation down the opposing, master graben fault. Rock rotations in this graben are not simple topple failures.

3. Clear examples of changes in master fault polarity along strike in echelon grabens. These dip reversals apparently control the geometry of deformed strata in the stepover regions between graben faults, leading to an obvious and mechanically simple context for stepover (relay and ramp) genesis.

4. Systematic differences in the typical dip direction of master faults in the inner vs. outer domains. It appears that master faults of many grabens located in the inner domain dip west, toward the Colorado River, whereas those in the outer domain mainly dip east, away from the river. These domains are separated by a subtle topographic high.

Precision measurement of topography across several grabens [15] also demonstrates an asymmetry of post-faulting topography that correlates with that inferred from differences in offset across the grabens (Fig. 1). These new constraints [15] suggest to us that the Canyonlands grabens are not symmetric in cross section, but instead can show a pronounced asymmetry. While the implications for graben genesis and mechanics are still being developed, these structures are yielding new clues to the mechanics of shallow
crustal extension of planetary surfaces.

Implications for Planetary Grabens.

The Canyonlands grabens have been used for many years as the type example of a simple planetary graben [e.g., 16], with the expectation that graben widths, scaled to fault dip and thereby to graben depths, provide information on the subsurface stratigraphy [17]. This notion was recently tested by Schultz and Fori [18] by measuring and plotting lengths of shallow plateau grabens from the Candor Mensa area of Valles Marineris. They found no evidence in the cumulative-length distribution plots for mechanical discontinuities inferred by other workers [17], suggesting either that the discontinuities do not exist or that the fault-population statistics are not sensitive to their presence. These results are comparable to those of Dawers and Anders [19] for a well-constrained population of normal faults in terrestrial tuff. Our new findings on Canyonlands graben asymmetry, combined with high-quality studies of terrestrial fault sets in the literature, suggest to us that the relationship between graben length or width to subsurface stratification may not be as straightforward as sometimes portrayed in the planetary literature.


Fig. 1. Precision microtopography (± 2 m) across two transects, showing asymmetric graben walls and offsets along several grabens of variable size. RLC, Red Lake Canyon; CC, Cyclone Canyon; DL, Devils Lane; DP, Devils Pocket. Top, grabens in the outer domain; bottom, inner domain.