Formation of Ganymede Grooved Terrain by Sequential Extensional Episodes: Implications of Galileo Observations for Regional Tectonics Geoffrey C. Collins[1], James W. Head[1], Robert T. Pappalardo[1], and the Galileo Imaging Team. [1]Brown University, Dept. of Geological Sciences, Providence, RI 02912, Geoffrey_Collins@brown.edu.

Ganymede's most distinctive surface features are the regions of bright grooved terrain that occupy half of the satellite's surface. Understanding the events that led to the formation of the grooved terrain we see today is essential to understanding much of the unique history of Ganymede. The nature of the extensional deformation that formed the grooves seen in the Galileo images is described as horst-and-graben and tilt-block normal faulting by Pappalardo *et al.* [1]. This abstract describes the sequence of extensional events that formed the grooved terrain surrounding the Galileo G1 target area in Uruk Sulcus (11°N 169°W). This sequence of events is a crucial piece of information for examining the driving mechanisms of groove formation, which may be related to Ganymede's thermal and orbital evolution [2]. To unravel this sequence of events, we first determine the stratigraphic relationships between sets of grooves observed at high resolution by Galileo, and then use these stratigraphic principles to extend the analysis to the surrounding areas imaged at lower resolution by Voyager.

Previous authors have suggested sequences of events for the formation of grooved terrain based on Voyager data [3,4]. These models have the common sequence of throughgoing fractures subdividing the terrain into isolated polygons, which are subsequently flooded by bright ice-volcanic material. Some of these flooded polygons are then individually deformed by local processes to create the mosaic of grooves of different orientations seen today in Uruk Sulcus. For the independent deformation of adjacent polygons to take place, they must have been structurally isolated from each other. This would predict that at a T-termination of one groove against another, the vertical bar of the T would be younger. In the high-resolution Galileo images of Uruk Sulcus it is clear that instead the grooves forming the crossbar of the T are younger, as they progressively break apart the older terrain and truncate features such as craters. The new grooves along the crossbar of the T are being formed at the expense of the older grooves through a process of tectonic resurfacing [5]. The evidence of the older structures is obscured by the formation of the new structures. Thus, the grooved polygons are remnants of older terrain which have been cut apart and isolated from each other by areas of more recent deformation. The patterns of grooves in bright terrain can be explained by the sequential superposition of areas of extensional faulting which tectonically obscure the underlying groove sets.

In the Galileo Uruk Sulcus target area, the oldest episode of deformation can be seen in the heavily cratered areas in the NE and SW corners. The grooves here trend NE-SW and have a subdued morphology, with little topographic expression. The second episode of deformation trends N-S and exhibits both this subdued morphology and a sharper-appearing horst-and-graben morphology. The youngest episode of deformation can be observed in two distinct bands cutting NW-SE across the target area, with a possible transtensional connecting zone between them [1,6]. Ridges in these zones trend NW-SE and exhibit a tilt-block morphology [1]. This stratigraphic sequence can be extrapolated to broader regions using the Voyager data. The Galileo target areas serve as anchors of known stratigraphy within the Voyager data, allowing a fiftyfold increase in the area covered by this analysis over the area of the Galileo observation. In Uruk Sulcus and areas of grooved terrain to the northwest, the stratigraphy observed in the Voyager images is (fig. 1): 1) subdued grooves trending NE-SW, 2) subdued grooves with lanes of more prominent grooves trending N-S, 3) prominent grooves trending NW-SE. This suggests a counterclockwise rotation of tensional stresses through time from NW-SE to NE-SW.

This sequence differs from earlier models [3,4] which would have predicted that the oldest grooves are those trending NW-SE, which are the youngest grooves in this model. The model in [4] also predicts that these grooves are reactivated as the youngest episode of deformation, consistent with this model. The previous models also predict that the grooves within grooved polygons, trending NE-SW and N-S, represent a younger episode of deformation associated with the flooding of the terrain by bright material, and that these grooves formed in isolation from grooves on other polygons. The model presented here is based on the observation that the grooves on these polygons are actually the oldest grooves in the Uruk Sulcus target area. These grooves represent an older tectonic fabric that originally covered larger areas of Uruk Sulcus and has since been tectonically resurfaced by younger groove formation, thus isolating the remnants of this terrain into individual polygons.

The sequence of events in Uruk Sulcus shows that groove orientation and the style of deformation have changed through time. Changes in the style of deformation through time may indicate changes in the properties of the underlying lithosphere, the strain rate, or the total strain. The lithosphere of the grooved terrain will be progressively thinned by repeated episodes of extension if they are rapid enough for the temperature gradient to remain elevated from one episode to the next. Irregularities in lithospheric thinning may provide the impetus for the change from horst-and-graben faulting, dominant when the brittle/ductile transition is more uniform [7], to tilt-block faulting following continued extension.

Possible driving mechanisms for groove formation include stresses from mantle convection or from surface expansion due to freezing of the mantle and subsequent thermal evolution [8], possibly modified by tidal stresses due to interaction with the other Galilean satellites. The greater magnitude of stresses caused by planetary expansion versus mantle convection led Murchie *et al.* [4] to favor this mechanism for the formation of grooved terrain. The consistency of stress directions in the sequence over more than a thousand kilometers along Uruk Sulcus may argue against mantle convection stresses as the driving mechanism for groove formation, as these stresses depend on the surface location relative to the upwelling and downwelling regions of the convection cells. Stresses due to global expansion, modified by tidal interactions, may be able to create such consistent stresses along the length of Uruk Sulcus.

References: [1] Pappalardo *et al*. (1997) this volume; [2] McKinnon and Parmentier (1986) in *Satellites*, Burns and Matthews, eds., U. of Arizona Press, 718-763; [3] Golombek and Allison (1981) *Geophys. Res. Lett*. 8, 1139-1142; [4] Murchie *et al*. (1986) *J. Geophys. Res*. 91, E222-E238; [5] Head *et al*. (1997) this volume; [6] Senske *et al.* (1997) this volume; [7] Pappalardo and Greeley (1995) *JGR* 100, 18,985-19,007; [8] Zuber and Parmentier (1984) *LPSC XIV* in *JGR* 89, B429-B437.

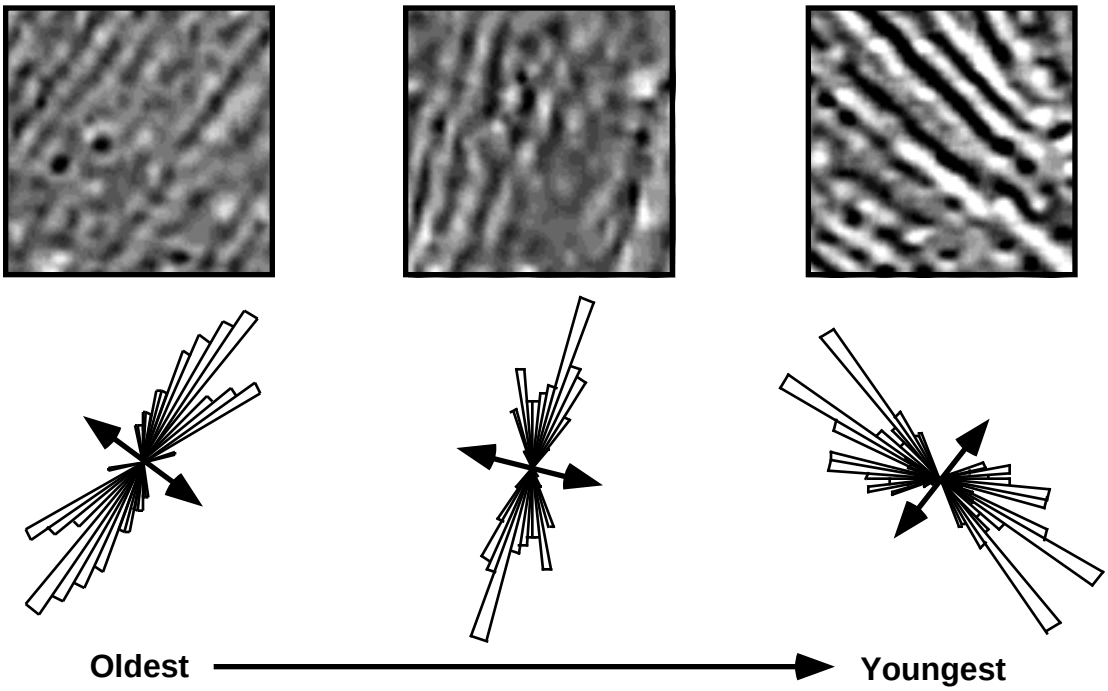

Figure 1: Sequence of groove formation in Uruk Sulcus. Rose diagrams show groove orientations and inferred extension direction (arrows). Voyager images above rose diagrams show typical morphology (at ~1km/pixel) of these groove units.