DRIVING MECHANISMS FOR GROOVED TERRAIN FORMATION ON GANYMEDE: COMPARISON OF THEORY TO GLOBAL GROOVE DATABASE. Geoffrey C. Collins; Physics and Astronomy Dept., Wheaton College, Norton Massachusetts 02766. gcollins@wheatoncollege.edu

Introduction: At some midpoint in Ganymede's history, it went through a dramatic period of intense resurfacing, leaving behind the grooved terrain that covers two thirds of the surface. Many models have been proposed to explain what happened on Ganymede to produce the grooved terrain; the ideas that have survived initital *Galileo* data analysis include internal differentiation [1, 2], an episode of enhanced tidal heating and internal melting [3, 4], hemispheric-scale convection cells [5], nonsynchronous rotation [6], and/or tidal despinning followed by polar reorientation [7]. Evidence from the population of viscously relaxed craters on Ganymede indicates that the heat flow through the surface dropped dramatically after grooved terrain formation [8]. The correlation between grooved terrain formation supports models involving a heat pulse [3, 9]. Evidence for nonsynchronous rotation occurring in Ganymede's past comes from observations of the observed vs. expected crater distributions [6] but it is unknown whether this rotation was contemporaneous with grooved terrain formation.

My goal is to address the likelihood of these theoretical driving mechanisms for grooved terrain formation by using the record of the grooves themselves. The grooved terrain represents a history of strain on the surface which can tell us about the forces driving the resurfacing event. The strain history is composed of three parts, the strain magnitude, the strain direction, and the time sequence.

Strain magnitude: The strain magnitude in grooved terrain has been measured in two different ways. Almost all large craters start very close to circular, and any crater that has been deformed by grooved terrain formation makes an ideal strain marker. Pappalardo and Collins [10] developed a method of using craters as strain markers that disentangles the pure shear and simple shear components of the strain. Using this method, we have found some narrow sets of high-relief grooves that have extended by over 50% (and one well over 100%). A more areally extensive set of moderate-relief grooves exhibits 15% extensional strain. Other areas of bright terrain with very subdued groove morphologies have insignificant strain (0% is in the error bars). These strain measurements using crater geometry have been backed up by independent measurements using the geometry of the normal faults themselves [11].

The large amount of extension observed on Ganymede may be driven by internal melting during a past heating event, which could produce about a 1.5% increase in surface area [3], or by internal differentiation, which would produce an increas in surface area of up to 6% [2]. By taking the strain measurements made in high resolution Galileo observations and applying them to similar areas of bright terrain seen globally at lower resolution, we are able to estimate the total amount of extension represented by grooved terrain. The exact answer depends on the details of assumptions about which kind of terrain observed at moderate resolution represents what amount of strain observed at high resolution (see Figure 1 for an example), but the estimate of surface area increase is nominally 8%, and does not go lower than 5% without really stretching the assumptions. Thus, examining models of interior differentiation in more detail may be a promising avenue. However, just because we don't see evidence for contractional deformation doesn't mean it can't be hiding through compaction and creep of the lithosphere elsewhere, so the observed surface area expansion is not a

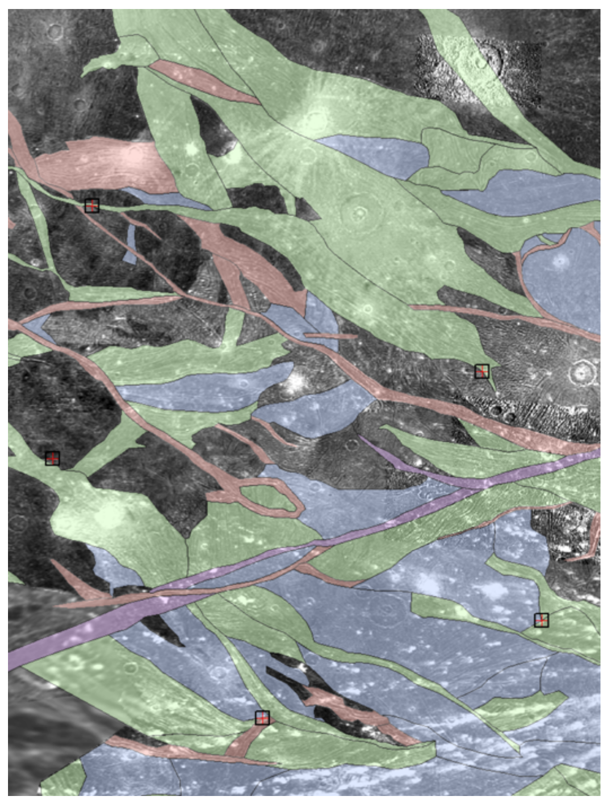

Figure 1. Portion of western Sippar Sulcus showing division of grooved terrain into strain categories. Red: high (50-100 %); Green: medium (10-25%); Blue: low (1-5%); Purple: planks (1-5% or crustal spreading [20]).

completely hard constraint at this point.

Strain direction: The direction of least compressive stress is a fundamental prediction of many models to explain the formation of grooved terrain. Measuring this paleo-stress direction involves linking the observed grooves to a stress orientation. At high resolution, the features that make up grooved terrain appear to be almost all extensional features [12], and quantitative analysis of craters as strain markers has backed up this morphological interpretation [10]. Some transtension and strike-slip motion has been observed [10, 12, 13], but the motions appear to be relatively small. No unambiguous contractional features have been observed. Thus, if grooves predominantly represent extensional strain, the direction of least compressive stress should have been predominantly orthogonal to the grooves at the time of their formation.

A GIS database of the locations and orientations of all the grooves on Ganymede observable with current data has been assembled [14], and recently revised based on the updated control coordinate network [15]. The azimuths of 180,000 line segments in the database have been calculated and these can then be compared to theoretical predictions for orientations of extensional structures due to different driving mechanisms.

Time sequence: Cross-cutting relationships between groove sets can be a guide for unraveling the history portion of the strain history. First, the groove database has been separated into groove sets based on co-location, orientation, and morphology (a preliminary version of this is in [16]). Next, these groove sets need to be put into a time sequence. This can be done manually for small areas (e.g. [17]), but with several thousand groove sets across the globe, a full manual sort is prohibitively confusing. Computers can assist the time sequence sorting process, by finding the best sort through a large, sometimes ambiguous data set [18]. The investigator keeps track of local cross-cutting relationships (and the confidence in those interpretations), and the computer takes that information and performs a sort that preserves the most confident interpretations. This has been tested in a couple of large and complex regions of Ganymede (e.g. [19]). Several regions of Ganymede have been sorted into time sequences, but these are still in the process of being linked together into a global picture of the time sequence of grooves. However, we do have as a first product a global map of the youngest sets of grooves, which can be compared to theoretical stress predictions.

Comparison to theory: The positions and orientations of line segments for each age category of grooves serve as input for a computer program which takes each line segment and calculates how well it fits the orientation expected from a variety of driving mechanisms. All of the line segments are totaled up to provide a least squares fit between a global stress field and the observed grooves. Currently stresses due to differentiation and nonsynchronous rotation are being tested for a variety of tidal axis positions. Polar wander stresses will be incorporated soon. So far, the best fit stresses to the youngest set of grooves on Ganymede is stresses due to differentiation if the tidal axis is rotated around the equator from its current position (Figure 2). Current work involves going farther back in the time sequence, to see if this relationship holds up, and if there is a logical progression of stresses with time (as one would expect with if nonsynchronous rotation is a factor).

References: [1] Squyres, *GRL* (1980); [2] Mueller and McKinnon, *Icarus* (1988); [3] Showman *et al.*, *Icarus* (1997); [4] Zuber and Parmentier, *JGR* (1984); [5] Bianchi *et al.*, *Icarus* (1986); [6] Zahnle *et al.*, *Icarus* (2001); [7] Murchie and Head, *GRL* (1986); [8] Schenk, *Workshop on Ices, Oceans, and Fire* (2007); [9] Bland and Showman, *Workshop on Ices, Oceans, and Fire* (2007); [10] Pappalardo and Collins, *J. Struct. Geol.* (2005); [11] Michaud and Collins, *LPSC* (2007); [12] Pappalardo *et al.*, *Icarus* (1998); [13] DeRemer and Pappalardo *LPSC* (2003); [14] Collins *et al.*, *LPSC* (2000); [15] Becker *et al.*, *LPSC* (2001); [16] Patterson *et al.*, *LPSC* (2007); [15] Collins *et al.*, *Icarus* (1998); [17] McBee and Collins, *LPSC* (2002); [18] Crawford and Pappalardo, *Astrobiology* (2004); [19] Martin *et al.*, *LPSC* (2006); [20] Head et al. *GRL* (2002).

Acknowledgements: This work is supported by NASA OPR grant NNG05GG96G.

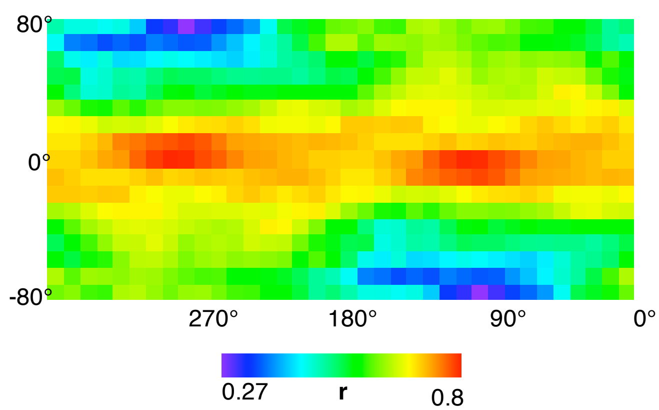

Figure 2. Correlation between observed groove orientations and stress field expected from internal differentiation, presented as a map of potential tidal axis positions. Best fits occur when the tidal axis is on the equator, rotated about 90° from its current position.