BRIGHT TERRAIN TECTONICS AND THE EVOLUTION OF GANYMEDE. Geoffrey C. Collins, Physics and Astronomy Dept., Wheaton College, Norton MA 02766, gcollins@wheatoncollege.edu.

Introduction: The bright grooved terrain that covers two thirds of the surface of Ganymede records a dramatic period in Ganymede's evolution. Many models have been proposed to explain what happened on Ganymede, including 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]. All of these mechanisms have also been proposed in one way or another to have affected other satellites in the outer solar system. Like its smaller cousins Enceladus, Dione, Tethys, Miranda, and Ariel, Ganymede's surface exhibits both old, heavily cratered terrain and younger terrain resurfaced by tectonic (and possibly also cryovolcanic) activity. As a large type locality for icy satellite tectonic processes, it is important to understand the origin of grooved terrain on Ganymede.

The record of bright grooved terrain: The first step in observationally addressing the evolution of Ganymede is to decipher the message recorded by the grooved terrain. The lineaments that make up grooved terrain are divided into thousands of "sets," where grooves share a similar orientation and morphology within each set. Their cross-cutting relationships show that the stress direction and strain magnitude has changed over time in various regions of Ganymede. Some groove sets are extensive, covering thousands of kilometers in length. In order to link grooved terrain observations with the theoretical predictions that come from various models of Ganymede evolution, we must compile a strain history of Ganymede. This compiled strain history, representing the best of our observational knowledge so far, answers the questions: What was the direction of least compressive stress in the lithosphere while grooves were forming? How much did the surface deform in response? How did the direction of stress change over time? Let us address these questions in turn.

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, such as tilt block normal faults or horst and graben sets [8], and quantitative analysis of craters as strain markers has backed up this morphological interpretation [9]. Some transtension and strike-slip motion has been observed [8, 9, 10], 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 database of the locations and orientations of all the grooves on Ganymede observable with current data has been assembled [11], and recently revised based on the updated control coordinate network [12]. This database serves as the foundation for further understanding of global groove tectonics.

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. We have developed a method of using craters as strain markers that disentangles the pure shear and simple shear components of the strain [9]. 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 [13].

Cross-cutting relationships between groove sets can be a guide for unraveling the history portion of the strain history. First, we have taken the groove database and separated it all into groove sets based on co-location, orientation, and morphology (a preliminary version of this is in [14]). Next, these groove sets need to be put into a time sequence. This can be done manually for small areas [15, 16], 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 [17]. 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. [18]), and we are presently working our way up to a full global groove sequence sort.

Preliminary results: There are two pieces of observational information that we can use to discriminate among the proposed mechanisms for grooved terrain formation. One of them is the total amount of strain represented by grooved terrain, and the other is the stress orientations and their evolution with time.

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 have been 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, but the estimate of surface area increase is nominally 7%, and does not go lower than 4%. 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 [19], so the observed surface area expansion is not a completely hard constraint at this point.

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 a global map of the youngest sets of grooves, and these have been run through a comparison with various sources of global stress fields to find the least-squares fit of a stress field to the observed grooves. So far, the best fit stresses to the youngest set of grooves on Ganymede is stresses due to differentiation and 60° of nonsynchronous rotation. As we go farther back in the time sequence, we will see if this relationship holds up, and if there is a logical progression of stresses with time (as one would expect with nonsynchronous rotation).

The limitation in much of this work is that, though we have moderate resolution (1-3.5 km/pixel) data for most of the surface of Ganymede, we must interpret the strain and time sequence details based on several small high resolution "postage stamps" collected by the Galileo mission. A future mission to the Jupiter system can collect much more uniform and high resolution data to help us decipher the history of Ganymede and its implications for the mechanisms that drive icy satellite tectonics.

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] Pappalardo *et al.*, *Icarus* (1998); [9] Pappalardo and Collins, *J. Struct. Geol.* (2005); [10] DeRemer and Pappalardo *LPSC* (2003); [11] Collins *et al.*, *LPSC* (2000); [12] Becker *et al.*, *LPSC* (2001); [13] Michaud and Collins, *LPSC* (2007); [14] Patterson *et al.*, *LPSC* (2007); [15] Collins *et al.*, *Icarus* (1998); [16] McBee and Collins, *LPSC* (2002); [17] Crawford and Pappalardo, *Astrobiology* (2004); [18] Martin *et al.*, *LPSC* (2006); [19] Pappalardo and Davis, this meeting.

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