The origin of grooved terrain on Ganymede

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Introduction
Grooved terrain covers almost 2/3 of Ganymede’s surface and records an intense resurfacing event at some point in the middle of solar system history. Inscribed into the grooved terrain is a pervasive and intricate network of faults. At high resolution, these faults have been shown to accommodate horizontal extension and shear strain [1]. Finding the causal mechanism behind the stress that created these faults is key to understanding the origin of grooved terrain on Ganymede.

Presented here are the results of a detailed analysis of Ganymede grooved terrain tectonics, with the goal of finding the mechanism responsible for grooved terrain formation. Several mechanisms have been proposed in the past, including differentiation [2,3], internal melting [4,5], degree-two mantle convection [6], diurnal tides and nonsynchronous rotation [4], and despinning followed by true polar wander [7]. Stress orientations and strain magnitudes predicted from the proposed models can be compared to the tectonic record preserved on Ganymede’s surface.

Strain magnitude
Detailed stereo images obtained in a small area of Uruk Sulcus allowed strain measurements using the geometry of tilt block normal faults on the surface, indicating ~50% extension in this region [8]. Strain measurements in five other high resolution target areas were accomplished using craters as strain markers [1], and have been confirmed using normal fault geometry methods [9]. The results show narrow fault zones accommodating 50% to 150% extension. Areas of more subdued grooves show 15% extension, and other bright terrain areas marked only by subtle lineaments show < 5% extension.

Such strain measurements are not possible for the vast majority of grooved terrain due to low resolution image coverage. However, there is a marked difference in the groove morphology that can be observed at low resolution between areas of high strain and low strain. Figure 1 shows a map of grooved terrain on Ganymede classified into three strain classes: high strain (similar to areas observed with 50-150% extension), moderate strain (similar to areas observed with ~15% extension), and low strain (similar to areas with 0-5% extension). A fourth special class shows smooth linear deposits which may either be low strain cryovolcanic deposits or Europa-like spreading centers [10].

By summing the area covered by all grooved terrain within a certain strain category, we can estimate the net change in global surface area represented by each of these classes of grooves. An expansion in global surface area of 6.4% to 20.6% is calculated for the lower and upper bounds of the strain estimates. Mueller and McKinnon [3] calculated a net change in surface area of about 6% from internal differentiation, consistent with the lower end of the observed scale, but calculated surface area expansion due to internal heating and melting would be much lower, about 2% [4].

Stress orientation
The locations and orientations of about 180,000 groove segments visible in the global mosaic of Ganymede are stored in a GIS database. These groove segments can then be quantitatively compared to the local orientation of stresses predicted by various proposed groove-forming mechanisms. Stress orientations due to changes in Ganymede’s figure (as a result of changes in the tidal or rotational distortions) are calculated and the orientation of least compressive stress is compared to the azimuth of local groove segments. Tensile fractures should form perpendicular to the least compressive stress direction, so a correlation
coefficient is calculated based on the fit of all the grooves to a calculated stress field. The best fit stress field (out of several models tried so far) is the one predicted by the internal differentiation of Ganymede, with the tidal axis offset about 70 degrees directly east of its current position. Differentiation concentrates mass toward the interior, leading to a simultaneous reduction in the tidal and rotational distortions.

**Time sequence**

Using cross-cutting relationships and custom software to assist in time sequence sorting of large numbers of units [11], all of the grooves have been sorted into three relative age categories: youngest, intermediate, and oldest. Figure 2 shows a map coded by the relative ages of grooved terrain units. Though there are significant local changes in groove orientation with time, and there are fascinating visual patterns that emerge as a result of changes through time, there is surprisingly little change in overall correlation with tidal stress models with time. Differentiation is the best fit stress field for all time categories.

**Conclusion**

The best observational fit for the origin of grooved terrain on Ganymede, in terms of surface strain, stress orientations, and change through time, is interior differentiation leading to global expansion and a reduction in tidal and rotational distortions. One caveat is that the algorithm for calculating the correlation treated all faults as dependent only on least compressive stress direction. Work currently in progress will compare the fault orientations to the full stress field in order to calculate slip tendency, which may modify the fit somewhat.

Delivering internal differentiation until the midpoint of Ganymede’s history may be geophysically difficult to accomplish. If Ganymede was only partially differentiated for the first part of its history, perhaps capture into a Laplace-like resonance [4] could provide the thermal trigger for differentiation. It is interesting to contemplate that Ganymede’s unique network of grooved terrain may be a record of its unique history as a large satellite captured into a strong orbital resonance.

**References**


![Figure 1. Strain categorization map of grooved terrain. Red is high strain, green is intermediate, blue is low. Light blue areas are smooth linear deposits [10] (see text). White areas are unclassified due to low resolution. Brown is dark terrain.](image1)

![Figure 2. Time sequence map of grooved terrain. Red is youngest, green is intermediate, blue is oldest. White areas are unclassified; brown is dark terrain.](image2)

Both figures are equal-area cylindrical projection, with the side edges set to the longitude of worst resolution (300°W).