GLOBAL REORIENTATION OF GANYMEDE BY THE BASIN GILGAMESH: MODELS AND EVIDENCE FROM TECTONIC PATTERNS. *Scott L. Murchie and James W. Head III, Department of Geological Sciences, Brown University, Providence, RI, 02912.*

One of the important global forces that may affect icy satellites is global reorientation due to perturbations of their momental figures by young impact basins (1). As a negative mass anomaly, a young large impact basin will reorient a satellite so that the basin migrates toward the body's pole. Ganymede in particular may exhibit the effects of this global process, because it both possesses impact basins and has an abundance of tectonic features that may record stresses caused by global reorientation. It is the aim of this study to identify particular basins on Ganymede that may have significantly reoriented the satellite and to determine if there is geologic evidence that such reorientation occured.

The surface of Ganymede is dominated by two types of tectonic features, grooves and furrows (2,3). The grooves are believed to be extensional features, probably degraded grabens or tension cracks (4), and occur in sets of three major types (5,6): narrow elongate parallel bands of grooves (groove lanes), grooved polygons, and reticulate polygons. Groove orientations are structurally controlled on a regional scale by zones of weakness parallel and perpendicular to the furrow systems. However, on a global scale the orientations of major groove lanes follow a pattern not related to a single furrow set. The groove lanes in the anti-Jovian hemisphere are dominantly oriented NW-SE and those in the sub-Jovian hemisphere are dominantly oriented SW-NE. Bianchi et al. (7,8) found that the majority of grooves define two systems of small circles centered about poles at approximately 55^{o}N,73^{o}W and 70^{o}N,180^{o}W.

Ganymede was modelled as a differentiated ice-silicate spheroid (9) with a silicate core (radius 1826 km) and an ice mantle and lithosphere consisting of shells of ice VI, ice V, ice III, and ice I. The principal axes of the satellite's ellipsoid were calculated (10) and transformed to the principal moments of inertia. An impact basin on the planet was modelled as a cylindrical depression whose depth was taken from the empirical depth-diameter relationship for fresh lunar craters (11). The basin's moment of inertia was calculated as by Melosh (12). Global reorientation was modelled numerically by treating cumulative global reorientation as a series of incremental reorientations followed by adjustments of the tidal bulge and relaxation of the basin. The decaying inertial tensor of the basin and the satellite's tensor were added iteratively, and the new figure and principal axes were calculated from the eigenvectors of the summed tensors. For the simple case where reorientation occurred by a rotation about one of the principal axes of the ellipsoid, the maximum deviatoric stress was calculated (13). The damping time of Ganymede's librations about its new orientation was calculated (12) and is less than 2 yrs. The e-folding times (14) for relaxation of the tidal bulge and for isostatic adjustment of the crater by viscous relaxation (15) were determined. If the time for relaxation of the tidal bulge is much shorter than the lifetime of the basin, the satellite will undergo continuous reorientation whose cumulative effect would be analogous to a single reorientation by a much larger basin. Variables relevant to our calculations include viscosity (10^{14}P) (15,16,17) and shear modulus (3×10^{10} dyne cm^{-2}) (18) of Ganymede's icy mantle.

Gilgamesh (62^{o}S, 123^{o}W), which formed during later stages of grooved terrain emplacement (19), was found to be the only basin large enough possibly to have caused global reorientation. In a small basin model, a 9-km topographic depression was modelled to occur only within the middle 600-km ring, while in the large basin model the depression was modelled as occurring across the entire 900-km basin. The time range for relaxation of the bulge, bracketed by the times calculated for the large and small basin models, is 20-200 yrs; the time range for isostatic adjustment of the basin is 30,000-100,000 yrs. In the case of the small basin model, cumulative reorientation would equal about 15^{o}. In the case of the large basin model, reorientation would have the cumulative effect of causing the migration of the basin nearly to the pole, which clearly did not occur. Global reorientation would have been nearly equivalent to rotation of Ganymede about the major axis of its ellipsoid, and the trace of the paleonorth pole would have passed between the two poles of groove concentricity calculated by Bianchi et al. (7,8). The separation between these two poles of 40^{o}-50^{o} suggests that the grooves in fact define a global system of conjugate fractures. The pole defining the system would be at 70^{o}N,110^{o}W, within 4^{o} of the trace of the paleonorth pole and with an offset consistent with a small basin model. Such a global fracture system centered on the paleopole is consistent with fractures created by tidal despinning early in Ganymede's history (20).

We hypothesize that groove sets on Ganymede developed along ancient zones of weakness in the lithosphere, where fractures due to tidal despinning were parallel to one of the orthogonal zones associated with the furrows. During the later stages of grooved terrain formation, Gilgamesh was formed and reoriented the satellite. Three predictions about global geologic features follow from this hypothesis: a thickening of the lithosphere due to the low surface temperature around the paleopoles (19), areal patterns of groove orientation consistent with relict fractures due to tidal despinning, and a preferred orientation of younger groove sets consistent with stresses caused by global reorientation. By extrapolation of the hypothesis of a thicker polar lithosphere, we would expect less tectonic deformation of the thicker lithosphere in the areas of the paleopoles. Lucchitta (21) noted that the greatest concentrations of continuous dark terrain are Galileo Regio and a large antipodal dark area, both areas defining large parts of the paleopolar region. Tidal despining of a body with a constant volume would result in conjugate fractures bisected by lines of latitude equatorward of 48^{o} paleolatitude and fractures parallel to lines of paleolatitude poleward of 48^{o} (20). Groove lanes are dominantly at low oblique angles to paleolatitude lines in the area where conjugate fracture zones would be expected, and in the paleosouth polar region grooves are dominantly parallel to the paleolatitude lines (Fig. 1).

Stresses due to reorientation may have directed uniform tension due to global expansion and affected the orientations of younger grooves. We determined expected stress trajectories using the results of Helfenstein and Parmentier (13), and calculated that the greatest deviatoric stress would have been about 4.6 bars. This compares to a tensile strength of the icy lithosphere of a few to 20 bars (10,13,22). In Fig. 1 the area with deviatoric stress >3 bars is outlined and the trajectories of least compressive stress are shown. The youngest groove lanes are almost entirely at high angles to the trajectories, and are concentrated in the area of greatest deviatoric stress. The crater density on the largest of these young groove lanes, Mashu Sulcus, was measured by Plescia (pers. comm.). He found that it is one of

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the youngest groove lanes, and that its age is not significantly different from that of Gilgamesh ejecta.

In summary, we propose a partial tectonic history for Ganymede based on the results of this study and earlier work (4,5,6,7,8,19,20,21,23). The earliest tectonic event which has been recognized was tidal despinning (stage 1). Subsequently to despinning, the furrows were formed (stage 2); the despinning fractures either were resurfaced earlier or their surface expressions were obliterated by furrow formation. Later, groove formation began in older reactivated zones of weakness, preferentially where fracture zones from despinning and one of the orthogonal zones related to furrows were at low angles (stage 3). During the later stages of grooved terrain development the impact basin Gilgamesh was formed (stage 4), and global reorientation of about 20^{o} occurred. Associated stresses caused reactivation of older fracture zones and formation of the youngest groove lanes with a preferred orientation (stage 5).

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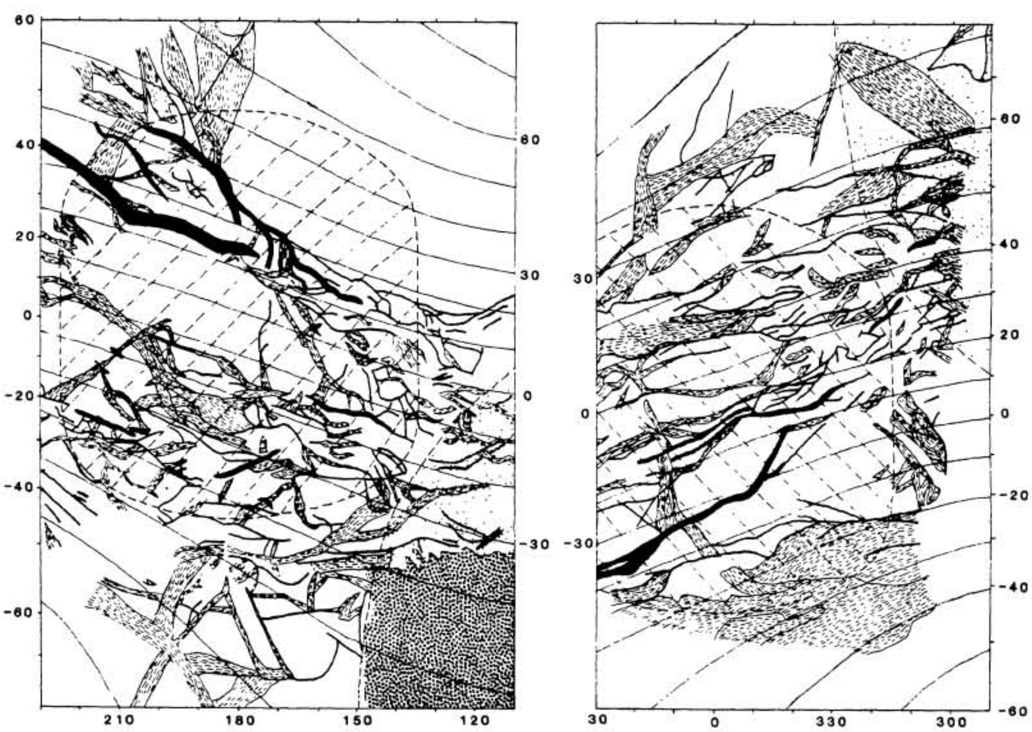

Fig. 1. Mercator projection of major groove lanes on Ganymede. The solid black lanes are youngest and cross-cut other groove sets. Other groove lanes are hatched, and throughgoing grooves are mapped using a heavier-weight line. The curved east-west lines are of paleolatitude, labelled in the center of the figure. The areas outlined by the dashed line experienced deviatoric stresses >3 bars due to reorientation; trajectories of the least compressive stress are shown in these regions. The lightly stippled areas experienced compressive stresses due to reorientation. Gilgamesh is shown in heavy stippling.

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