ORIGIN AND EVOLUTION OF FURROWS IN THE DARK TERRAIN OF GANYMEDE, Scott L. Murchie and James W. Head, Dept. of Geological Sciences, Brown University, Providence RI 02912.

Introduction. *Dark terrain* covering about half of the surface of Ganymede occurs as (a) several polygons thousands of kilometers in size and (b) a large number of smaller polygons. The large polygons contain the oldest class of pervasive tectonic features, called *furrows* (1). Separating the large dark polygons are bands and polygons of resurfaced *light terrain*, which together with many of the smaller dark polygons are pervasively cut by *grooves* forming *grooved terrain* that is interpreted to be of extensional origin (1,2,3,4,5). In many areas grooves developed by reactivation of older furrows (6,7) that in light terrain had been shallowly buried by high albedo material (7,8). Several models of furrow origin have been proposed, including (a) ring graben due to collapse of a giant crater (9), (b) fractures on a hemispheric-scale dome (10), and (c) reactivated tidal fractures (11). In this study, we examine structural and stratigraphic evidence to test these multiple hypotheses of furrow formation.

Geology of the furrows. The furrows form three hemispheric-scale systems of troughs, with the troughs in each system arranged approximately radially or concentrically to a central area (12). System I (Fig. 1), in the anti-Jovian hemisphere, occurs in the two largest dark areas (Galileo Regio and Marius Regio). Most troughs in this system have arcuate trends, and are arranged approximately concentrically to a faint higher-albedo palimpsest interpreted to be a degraded impact structure (13). The arcuate troughs are commonly several hundred kilometers long and 20-100 km apart, and often have higher-albedo deposits on their rims or are surrounded by smooth areas. In both cases, resurfacing materials appear to have emanated from the troughs (10). Other system I troughs are oriented approximately radially to the faint palimpsest, and are separable on the basis of length and morphology into two main classes. (a) Most of the radial troughs are 50-150 km long and terminate at arcuate troughs, suggesting a greater age for the latter structures. However, the higher-albedo and smooth deposits adjacent to the arcuate troughs bury parts of the short radial troughs. This relation suggests that although the arcuate troughs may be older, volcanism occurred later during their history. (b) A second, less abundant class of radial troughs is characterized by an average length of several hundred km, a greater width than the short radial troughs, and a variable age relation with the arcuate troughs. Long radial troughs in Galileo Regio are generally cross-cut by the arcuate troughs, suggesting a greater age of the long radial troughs, although there are clear examples of the opposite cross-cutting relation in Galileo Regio. In Marius Regio, the long radial troughs cross-cut the arcuate troughs, suggesting a younger age of the long radial troughs there. The termination relation of the short radial troughs and the variable age relation of long radial troughs with arcuate troughs indicates that, on a regional scale, both the arcuate and radial troughs of system I formed within the same period of time.

System II (Fig. 1), also in the anti-Jovian hemisphere, is dominated by linear troughs commonly 500-2000 km long and 200-800 km apart, arranged approximately radially to a pole near 22°S,135°W. A few troughs several hundred kilometers long (in SW Galileo Regio and SE Marius Regio) both intersect the radial troughs orthogonally and have a variable age relation with them. Both the radial and orthogonal troughs of system II consistently cross-cut and are younger than troughs of system I. System III occurs in the sub-Jovian hemisphere, and consists of degraded arcuate troughs several hundred kilometers long that are arranged approximately concentrically to a point near 60-70°N,40-50°W. The radius of the system is at least 90°. System III was interpreted by (1) to be the oldest of the three systems. This interpretation is supported by the occurrence of undeformed troughs from systems I and II within 40° of the center of system III.

Models of furrow origin. Predictions of the following models of furrow formation were tested for consistency with the observed structures and stratigraphy of furrow systems I, II, and III. *MODEL 1:* Ring graben formed by collapse of a large crater (9,14). *Predictions:* Concentric troughs without significant radial troughs, centered on a degraded impact. *MODEL 2:* Fractures caused by oscillating transient crater in fluid mantle (9,15). *Predictions:* Contemporaneous short arcuate and radial troughs, smooth central area. *MODEL 3:* Fractures on circular, hemispheric-scale dome (16). *Predictions:* Linear radial troughs, possibly some concentric troughs in central part of system. *MODEL 4:* Tidal fractures reactivated by volcanism and/or extensional tectonism (11). *Predictions:* Contemporaneous, linear, NE and NW-oriented troughs, with no apparent center of curvature. *MODEL 5:* Impact-generated ring graben reactivated by volcanism and/or extensional tectonism. *Predictions:* Dominant arcuate troughs centered on degraded impact, shorter radial troughs formed by fracturing of intervening lithospheric rings, variable age relations. *MODEL 6:* Fractures created by oscillating transient cavity, later reactivated by volcanism and/or extensional tectonism. *Predictions:* Short arcuate and radial furrows, contemporaneous or with variable age relation, possible central smooth area.

Results. The observed structural and stratigraphic properties of system I are consistent with the predictions of model 5 (reactivation of ring graben by volcanism and tectonism) and are inconsistent with predictions of the other models. Evidence for tectonism includes the common occurrence of short radial troughs terminating against arcuate troughs, suggesting failure in tension of lithospheric rings between the arcuate troughs. A possible driving mechansim is global expansion (13,17,18). Evidence for volcanism includes (a) the smooth and high albedo deposits adjacent to the arcuate troughs (10), and (b) the occurrence at the intersection of major troughs of an ovoidal feature interpreted by (19) to be diapiric in origin. The observed properties of system II are consistent with predictions of model 3 (radial extensional troughs formed on a hemispheric-scale dome) and are inconsistent with predictions of the other models. The size of the dome required to encompass the areal extent of the system (about 80° in radius) strongly suggests that the dome was related to large-scale internal convection. System III is generally consistent with models 2 and 5, impact-generated ring graben perhaps reactivated by tectonism and volcanism.

Synthesis of dark terrain geologic history. On the basis of the results of this study integrated with results of previous studies, we propose a preliminary geologic history of dark terrain. ***(1)*** The earliest event was the formation of a primitive crust soon after accretion 4.6 Gyr ago. This crust was then disrupted by fractures related to tidal despinning fractures (these were reactivated much later, during early stages of grooved terrain formation) (6,7,20). ***(2)*** By 4.0 Gyr ago, extensive resurfacing is believed to have buried preexisting surface morphology and to have formed present dark terrain (1,13). Because the relict tidal fractures were reactivated and deformed brittly during early grooved terrain formation, they may have been buried no deeper than about 10 km - the interpreted thickness of the brittle lithosphere at

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the beginning of grooved terrain formation (21). ***(3)*** Furrow systems I and III formed upon this dark terrain surface by impacts, which formed ring graben that were later reactivated by volcanism and extensional tectonism. ***(4)*** Subsequently system II formed on a hemispheric-scale dome possibly related to large-scale mantle upwelling. Furrow formation ceased by the beginning of grooved terrain formation at 3.8 Gyr (1,13). ***(5)*** Fractures developed in the furrows as well as tidal fractures continued to be reactivated for up to 10^9 yrs through the period of light and grooved terrain formation.

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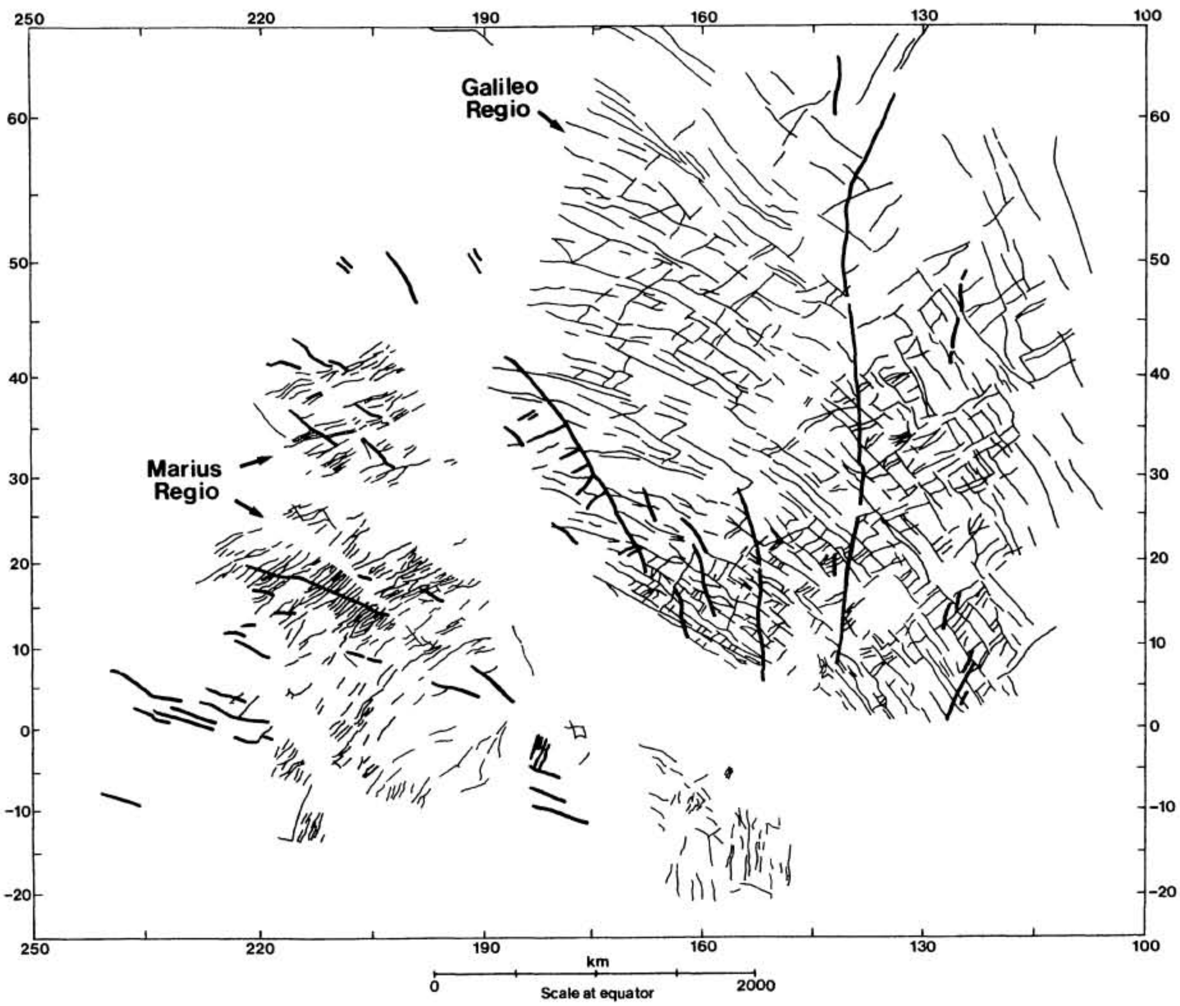

Figure 1. Mercator map of system I and II furrows, digitally compiled from maps of furrows on USGS shaded relief quadrangle base maps. System I furrows are shown in light-weight lines; system II furrows are shown in heavier-weight lines.