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Tectonic and Volcanic Evolution of Dark Terrain and Its Implications for the Internal Structure and Evolution of Ganymede

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Furrows in ancient dark terrain on Ganymede form three systems that are each hemispheric or greater in scale. The oldest of the systems, designated system III, is dominated by approximately concentric troughs centered on about 60°N,50°W. System I, in the anti-Jovian hemisphere, contains concentric and subradial furrows arrayed around a large, degraded palimpsest centered at 15°S,165°W. Furrows in each system formed on and locally are buried by dark volcanic materials that embay and infill preexisting topographic features; they crosscut extremely few well preserved older craters; and they occur on surfaces having significantly different relative crater ages. System II, also in the anti-Jovian hemisphere, contains widely spaced, radially arrayed furrows commonly 500-2000 km in length, which are organized around a large area of dark smooth resurfacing material, intense dark terrain fracturing, and some of the globally oldest light material. The total thickness of dark terrain resurfacing, estimated using the stratigraphy of different dark material deposits and the rim heights of the largest crater size class whose density was depleted by each deposit, is probably in the range of 3-8 km. Multiple models of the origin of each furrow system were tested using observed geologic features and patterns. Systems I and III were found to be most consistent with reactivation of impact-generated, multiringed structures by endogenic global extension, during a period of widespread dark material volcanism that obliterated a dense, ancient crater population. System II was found to be most consistent with fracturing of a single, circular, isostatic uplift covering an entire hemisphere. On the basis of geologic observations and interpretations and theoretical models of convection in spheres, it is hypothesized that the uplift developed by long-term warming of the upwelling current of a single axisymmetric convection cell in an initially cooler, undifferentiated interior. Such warming would also have created global expansion and supplied the tensional stress inferred to have formed systems I and III. This hypothesis is supported by the concentration around the center of system II of intense fracturing and relatively young dark volcanic deposits, suggestive of high lithospheric heat flow, lithospheric thinning, and stress concentration. An observed long-term decrease in the width of extensional tectonic features interpreted to be of endogenic origin is also consistent with lithospheric thinning due to warming of a cool interior.

INTRODUCTION

Approximately half of Ganymede's surface consists of heavily cratered dark materials which occur in polygonal blocks outlined by younger, resurfaced light terrain [*Smith et al.*, 1979*a*,*b*]. Much of the light terrain has been pervasively cut by U-shaped tectonic troughs or "grooves," forming "grooved terrain." Also, some small dark polygons have hummocky or pervasively fractured surfaces ("reticulate terrain") that were deformed during early stages of grooved terrain formation [*Lucchitta*, 1980; *Shoemaker et al.*, 1982; *Casacchia and Strom*, 1984; *Murchie et al.*, 1986, 1989*b*; *Murchie and Head*, 1988]. Large dark polygons, commonly thousands of kilometers in size, have older surfaces cut by sets of linear and arcuate "furrows," and are more heavily cratered than are other terrains on Ganymede. However, most measurements indicate that at least for <40-km craters they are less cratered than is the surface of Callisto [*Smith et al.*, 1979*b*; *Passey and Shoemaker*, 1982; *Shoemaker et al.*, 1982; *Woronow et al.*, 1982].

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Furrows are linear to curvilinear dark terrain troughs which vary regionally in width from 6 to 10 km, in spacing from 20 to more than 100 km [*Zuber and Parmentier*, 1984*a*; *Croft and Goudreau*, 1987], and in length from 30 to several thousand kilometers. The furrows' negative relief and grabenlike morphology suggest an extensional origin. Very few furrows crosscut well-preserved older craters, although dark resurfacing materials partially to completely bury furrows in many areas [*Casacchia and Strom*, 1984; *Croft and Strom*, 1985; *Croft and Goudreau*, 1987; *Murchie and Head*, 1987; *Murchie et al.*, 1988, 1989*b*; *Croft et al.*, 1990]. The furrows are arranged radially and concentrically to form three hemispheric-scale systems; the nomenclature used in this paper to describe the systems is that of *Murchie and Head* [1986]. System I, in Galileo Regio and Marius Regio in the anti-Jovian hemisphere (Figure 1), is dominated by arcuate furrows arranged crudely concentrically to a giant, very degraded palimpsest. This system also contains less abundant, subradially arranged furrows [*Smith et al.*, 1979*b*; *Passey and Shoemaker*, 1982; *Shoemaker et al.*, 1982; *Casacchia and Strom*, 1984; *Murchie and Head*, 1986, 1987, 1988; *Schenk and McKinnon*, 1987]. System II, also in the anti-Jovian hemisphere (Figure 1), contains troughs generally 500-2000 km in length that are arranged radially to a point about 1700 km east of the giant palimpsest [*Murchie and Head*, 1986, 1987, 1988; *Murchie et al.*, 1988]. System III occurs in