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Possible Breakup of Dark Terrain on Ganymede by Large-Scale Shear Faulting

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A system of arcuate furrows in Galileo Regio and Marius Regio, two large blocks of ancient dark terrain, has previously been proposed to be the remnant of an originally more concentric furrow set that was disrupted by shear. Estimates of the two regions' poles of furrow concentricity indicate a considerable westward offset of the Galileo Regio pole. These measurements suggest the possibility of about 500 km of left-lateral offset of the two areas; four additional, independent structural indicators support this hypothesis. There is evidence that shear deformation was concentrated along a major structural lineament which closely follows a small circle about 45° of arc of radius which encloses Galileo Regio, and that a smaller amount of distributed shear occurred across an adjacent 500- to 1500-km-wide band. There is also morphologic evidence for zones of minor right-lateral shear between central and southern Marius Regio and between Barnard and Nicholson Regio, and for a zone of minor left-lateral shear in Nun Sulci. Stratigraphic relations indicate that any major shear offsets occurred before and during the earliest stages of grooved terrain formation, before most grooves had formed and before virtually all light material had been emplaced. However, regionally dominant groove orientations are generally consistent with orientations expected for transtensional features: Either shear strain or the shear's driving mechanism may have had a long-term effect on patterns of deformation of Ganymede's lithosphere.

INTRODUCTION

The surface of Ganymede consists of older "dark terrain" and younger, resurfaced, higher-albedo "light terrain," each of which occupies about half of the satellite's surface. The light terrain is pervasively cut by linear, U-shaped tectonic "grooves," forming "grooved terrain" where grooves occur pervasively [*Smith et al.*, 1979*a*,*b*]. The formation and evolution of both grooves and grooved terrain have been explored in several previous detailed studies [e.g., *Lucchitta*, 1980; *Golombek and Allison*, 1981; *Parmentier et al.*, 1982; *Squyres*, 1982; *Murchie and Head*, 1985; *Bianchi et al.*, 1986; *Murchie et al.*, 1986].

Dark terrain is densely populated by craters having morphologies ranging from small bowl-shaped craters to large degraded palimpsests [*Smith et al.*, 1979*a*,*b*; *Passey and Shoemaker*, 1982], and it occurs as polygons tens to thousands of kilometers in size that are outlined by light grooved terrain. Smaller dark polygons 50-300 km in size commonly have surfaces that were pervasively deformed and cut by troughs during the early stages of grooved terrain formation, forming "reticulate" or lineated terrain [*Lucchitta*, 1980; *Casacchia and Strom*, 1984; *Murchie et al.*, 1986]. Larger dark polygons (Galileo Regio, Marius Regio, Nicholson Regio, Barnard Regio, Perrine Regio; Figure 1) were mostly unaffected by grooved terrain formation and contain a variety of older structures.

The most conspicuous dark terrain tectonic structures are furrows, which predate all grooves [*Smith et al.*, 1979*b*]. Furrows are linear to curvilinear troughs usually 6-10 km wide, tens to hundreds of kilometers long, and several hundred meters deep. Two major groups of parallel arcuate furrows, one in the anti-Jovian hemisphere (Figures 2*a*, 3, 4, and 5) and one in the sub-Jovian hemisphere (Figure 6), form hemispheric scale sets that are each arranged approximately concentrically [*Smith et al.*, 1979*b*; *Passey and Shoemaker*, 1982; *Shoemaker et al.*, 1982; *Zuber and Parmentier*, 1984*a*; *Casacchia and Strom*, 1984; *Murchie and Head*, 1986*b*, 1987; *Schenk and McKinnon*, 1987; *Murchie et al.*, 1988]. (The nomenclature of the furrow systems used herein is that of *Murchie and Head* [1986*b*].) System I arcuate furrows, in the anti-Jovian hemisphere, are observed (1) to be crudely centered on a faint, giant albedo feature commonly interpreted to be a giant palimpsest (at the arrows in Figure 5*a*), (2) to have a locally and regionally variable age relation with closely associated subradial to radial furrows (Figures 4 and 5*b*), and (3) to be grossly similar in spatial distribution to concentric rings of the basinlike feature Valhalla, on Callisto. Arcuate and radial furrows in system III (Figure 6) occur in all large dark blocks in the sub-Jovian hemisphere and are most well-preserved in Nicholson Regio. In the latter area, furrows are degraded compared to those in system I, leading *Smith et al.* [1979*b*] to conclude that system III is older. This interpretation is supported both by the occurrence of undeformed system I furrows within 40° of arc of the center of curvature of system III and by the greater crater age of sub-Jovian than anti-Jovian dark terrain [*Passey and Shoemaker*, 1982; *Murchie et al.*, 1988; also S. Murchie et al., Crater densities and crater ages of different terrain types on Ganymede, submitted to *Icarus*, 1988, hereinafter referred to as submitted manuscript].

Despite the gross similarities in spatial arrangement of furrow systems I and III to the Valhalla structure on Callisto, in detail there are important geological differences between the two types of features [cf. *Remsberg*, 1981]. Valhalla rings crosscut a large number of older craters, but extremely few craters are crosscut by furrows. Furrows in both systems I and III form sets up to 4000-5000 km in radius (Figures 4 and 6), whereas the Valhalla structure is only about 1500 km in radius. Furrows have been extensively modified by dark material resurfacing, and they formed on relatively crater free surfaces [*Passey and Shoemaker*, 1982; *Shoemaker et al.*, 1982; *Murchie et al.*, 1988; S. Murchie et al., submitted manuscript]. In contrast, Valhalla rings are only associated with comparatively minor resurfacing, and they occur on a much older, heavily cratered surface [*Remsberg*, 1981; *Passey and Shoemaker*, 1982]. Furthermore, all observed furrows are troughs, whereas many Valhalla rings are ridges or scarps. Thus, although furrows and Valhalla rings

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