SHEAR ZONES ON GANYMEDE: GLOBAL NATURE AND EFFECT ON GROOVED TERRAIN FORMATION, Scott L. Murchie and James W. Head, Dept. of Geological Sciences, Brown University, Providence, RI 02912.

Introduction. The surface of Ganymede possesses two main types of tectonic features. *Furrows* occur in old *dark terrain*, and form hemispheric-scale systems arranged approximately concentrically or radially to central areas (1-6). *Grooves* are U-shaped troughs concentrated in younger, resurfaced *light terrain*, and occur pervasively in large areas of *grooved terrain* that is interpreted to be extensional in origin (1,3,7-12). Arcuate furrows within large dark terrain polygons in the anti-Jovian hemisphere are arranged approximately concentrically, but the centers of curvature of the furrows in the different large polygons appear offset. This observation has been used to support the hypothesis that a more concentric set of anti-Jovian furrows was disrupted by shear zones (3,8,13). In a related study (5), we documented independent structural evidence for the existence of these shear zones, that indicates that major offsets occurred during the period (a) following furrow formation and (b) before and/or during earliest grooved terrain formation. Hemispheric-scale lineaments (heavy dashed lines, Fig. 1a), consisting of superposed throughgoing grooves and bands of grooves ("groove lanes" - 12) were interpreted to be reactivated strike-slip faults and bounding faults of zones of distributed shear. Offsets of non-furrow structures and block rotations observed at the lineaments have senses consistent with the senses of offset of the centers of furrow curvature for the large dark polygons. Lineaments I and II (Fig. 1a) were interpreted to define the boundaries of a zone of distributed left-lateral shear; the major portion of the left-lateral offset appears to have occurred across lineament I. Lineament III was interpreted to be the location of major right-lateral offset; east of 210°W it defines the northern boundary of a zone of distributed right-lateral shear. In this study we examine the global implications of the existence and ages of these shear zones, addressing the specific questions of (a) the continuation of the shear zones into the sub-Jovian hemisphere and (b) the effect of shear deformation on the (mostly younger) formation of grooved terrain.

Grooved terrain tectonic patterns. Bianchi et al. (14) measured groove orientations in large areas of both the sub-Jovian and anti-Jovian hemispheres. They recognized 11 large areas ("superdomains") that have one or two regionally dominant groove orientations and typically are bounded by throughgoing structures including the hemispheric-scale lineaments, These dominant orientations are represented in rose diagrams ("A"-"K") in Fig. 1. In addition, two types of preexisting structures have been interpreted to exert major control on regional groove orientations. *(a) Furrows.* In large areas of both hemispheres, regionally dominant groove orientations are parallel to arcuate furrows and/or to closely associated radial furrows (6,12,15). This observation was interpreted to indicate that groove formation commonly was initiated by the reactivation of furrows. *(b) Relict tidal fractures.* The effect on global orientation of the formation of the impact basin Gilgamesh (62°S,123°W) was modelled by (11). They found that formation of the basin would have perturbed the global moment of inertia and reoriented the satellite by 15-20°, placing the paleopole at 70-75°N,95°W. The paleopole is closely coincident with the pole of a system of small circles with which groove lanes form low angles globally. This relationship was interpreted to indicate that formation of many groove lanes was initiated by reactivation of relict tidal fractures symmetrical to the paleopole.

Constraints on shear zone geometry. Several studies of the formation of light terrain and grooved terrain (9,10,12) indicate that these terrains formed by resurfacing of downdropped dark terrain block by about 1 km of high-albedo material. None of the studies produced evidence for significant lithospheric spreading; furthermore, there is no evidence for large-scale compressional tectonic on Ganymede (1,3,7,8,9,10,12). Given the lack of evidence for creation or destruction of lithosphere, major shear zones or strike-slip faults would be expected to conserve lithosphere and therefore to follow globe-encircling small circles. In fact, the traces of the two suspected shear zones in the anti-Jovian hemisphere are approximately defined by the 20°N and 10°S lines of *paleolatitude* (shown as light dashed lines, Fig. 1a). This observation suggests that the shear zones, like many groove lanes, may have initiated by reactivation of relict tidal fractures.

Shear zone model. On the basis of the information given above, we propose (a) that the two major shear zones tentatively identified in the anti-Jovian hemisphere are segments of global shear zones whose traces are globe-encircling small circles, and (b) that deformation due to shear may have exerted some control on which zones of weakness were reactivated during grooved terrain formation. (a) may be tested by determining if there is evidence in the sub-Jovian hemisphere of left-lateral shear along the 20°N line of paleolatitude and of right-lateral shear along the 10°S line of paleolatitude. (b) may be tested by examining dominant groove orientations in the superdomains and determining if they are at high angles to the least principal stresses implied by the shear zones as well as parallel to relict fractures.

Global nature of shear zones. The light dashed lines in Fig. 1b show the locations of the 20°N and 10°S paleolatitude lines in the sub-Jovian hemisphere. In this hemisphere, as in the sub-Jovian hemisphere, there are hemispheric-scale lineaments consisting of superposed throughgoing grooves and groove lanes as well as linear discontinuities in regional groove orientation (heavy dashed lines, Fig. 1b). Strike-slip offsets of grooved terrain structures across the lineaments are observed. These include (a) 50 km of right-lateral offset of a N-S-oriented groove lane across lineament IIIa ("a", Fig. 1b) (7), and 70 km of left-lateral offset of a NNW-oriented groove lane across lineament IIa ("b", Fig. 1b) (8). Lineaments II and IIa both are characterized by left-lateral shear, are within 10-15° of 20°N paleolatitude, and are nearly parallel to the paleolatitude line. Similarly, lineaments III and IIIa both are characterized by right-lateral shear, are within 10° of 10°S paleolatitude, and are nearly parallel to the paleolatitude line. Therefore, we interpret both pairs of lineaments to be segments of global shear zones.

Relationship to grooved terrain formation. The relationship between dominant groove orientations in superdomains, orientations of relict fractures, and orientation of the least principal stresses implied by the senses of shear across the hemispheric-scale lineaments is shown in Fig. 1. Relict tidal fracture are oriented at low angles to the lines of paleolatitude (the latter shown as fine dashed lines). The ranges within the superdomains of measured or projected arcuate and radial furrow orientations are shown as arcs outside the rose diagrams. The orientations of the least principal stresses are shown as double-headed arrows. In 8 of the 11 superdomains ("A", "B", "C", "D", "F", "I", "J" and "K"), the one or two dominant groove orientations are parallel to arcuate and/or radial furrow orientations. In each case the dominant groove orientation (or one of the two) also is at high angles to the least principal stress. The two dominant groove

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orientations in superdomain "G" may be related to the orientation of either furrows or relict tidal fractures. One of the groove orientations is at high angles to the least principal stress due to right-lateral shear; the other groove orientation is at high angles to the least principal stress due to left-lateral shear. These results support the hypothesis that shear deformation exerted control over which orientations of relict fractures were reactivated during groove formation. Because shear offsets predated most grooved terrain formation (5), this control may have occurred by the selective weakening of relict fractures that were later reactivated during groove formation.

Summary. The two major shear zones tentatively identified in the anti-Jovian hemisphere (5) appear to be segments of global shear zones. The traces of the shear zones are approximated by independently determined small circles that may be related to relict tidal fractures. Groove orientations in large areas of grooved terrain are both parallel to relict fractures and at high angles to the least principal stresses implied by the shear zones. The latter relationship suggests that, although shear offsets predated most grooved terrain formation, strain due to the shear affected grooved terrain formation on a regional scale.

References. (1) Smith, B. et al., *Science, 206*, 927-950, 1979b. (2) McKinnon, W. and H. Melosh, *Icarus, 44*, 454-471, 1980. (3) Shoemaker, E. et al., in *The Satellites of Jupiter*, ed. by D. Morrison, Univ. of Arizona Press, Tucson, 1982. (4) Casacchia, R. and R. Strom, *J. Geophys. Res., 89*, B419-B428, 1984. (5) Murchie, S. and J. Head, this volume, 1987a. (6) Murchie, S. and J. Head, this volume, 1987b. (7) Smith, B. et al., *Science, 204*, 951-972, 1979a. (8) Lucchitta, B., *Icarus, 44*, 481-501, 1980. (9) Parmentier, E.M. et al., *Nature, 295*, 290-293, 1982. (10) Schenk, P. and W. McKinnon, *J. Geophys. Res., 90*, C775-C783, 1985. (11) Murchie, S. and J. Head, *Geophys. Res. Lett., 13*, 345-348, 1986. (12) Murchie, S. et al., *J. Geophys. Res., 91*, E222-E228, 1986. (13) Murchie, S. and J. Head, *Lun. Planet. Sci. XVII*, 581-582, 1986. (14) Bianchi, R. et al., *Icarus, 67*, 237-250, 1986. (15) Murchie, S. and J. Head, *Lun. Planet. Sci. XVI*, 599-600, 1985.

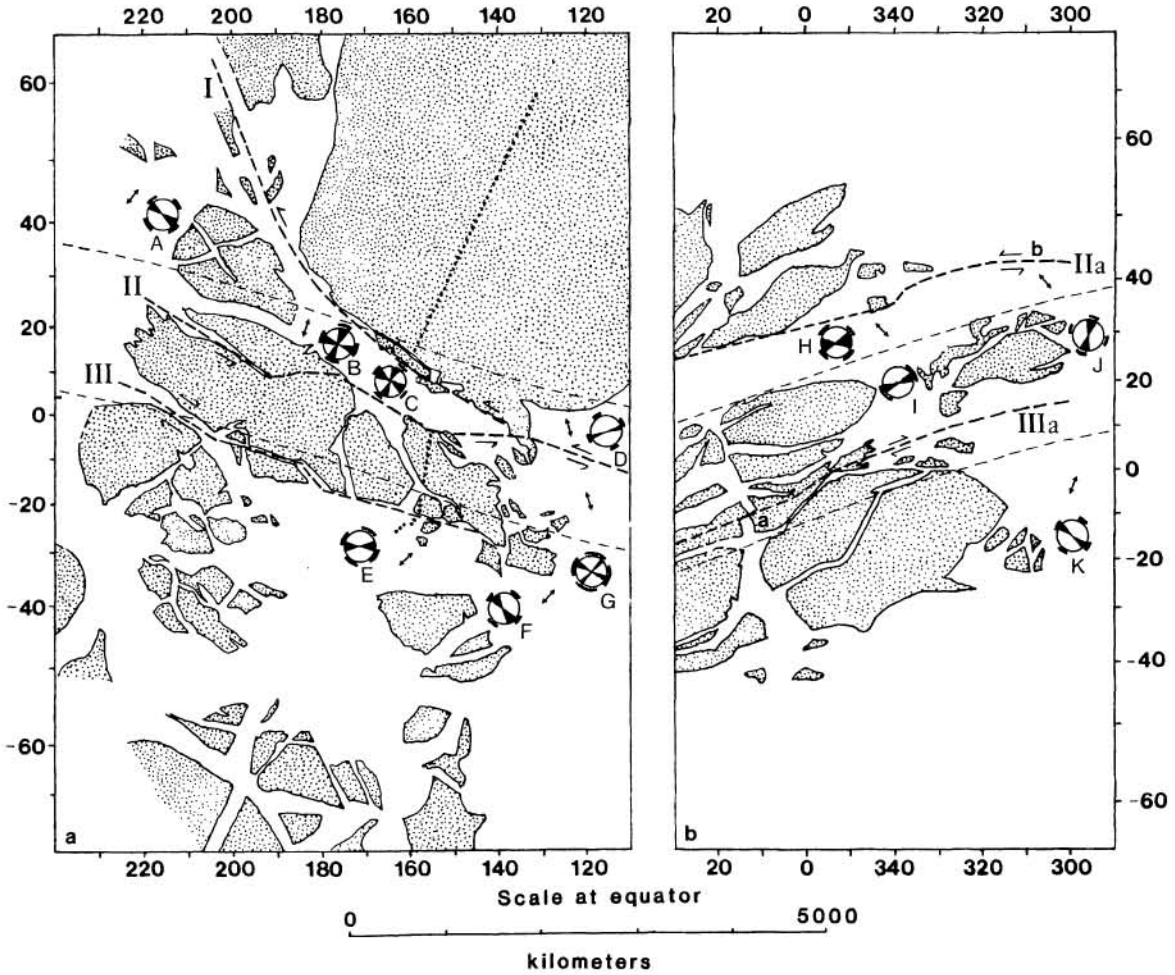

Fig. 1. Shear-related structures on Ganymede. Heavy dashed lines are locations of lineaments interpreted to be reactivated strike-slip faults. Light dashed lines are lines of paleolatitude. Capital letters identify superdomains, for which dominant groove orientations are shown in rose diagrams (adapted from 14). Arcs outside the rose diagrams show measured or projected orientations of arcuate and associated radial furrows in the superdomains. Double-headed arrows show orientations of the least principal stresses associated with shear. Small letters at right show the locations of grooved terrain structures observably offset across the lineaments. The dotted line is the post-furrow dark terrain trough offset across both shear zones (5).