GANYMEDE: MAJOR GEOLOGIC QUESTIONS AND FIRST RESULTS FROM THE GALILEO G1 AND G2 ENCOUNTERS.

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Introduction and Background: Prior to the acquisition of data during the Galileo encounters with Ganymede, major questions about geologic processes and the evolution of Ganymede were identified and these formed a basis for the targeting and data acquisition strategy for the imaging team [1]. Here we report on several of these major questions and the initial results revealed by the first two encounters [2].

(1) Mode of emplacement and evolution of dark terrain: The traditional model for the origin of dark terrain is that it is a nearly primordial, impact-generated surface; the lower density of impact craters than on Callisto has been attributed to viscous relaxation in an early warm lithosphere[3-5]. Alternatively, Voyager-based mapping and crater size-frequency studies suggest that resurfacing by low-albedo ice volcanism played a large role in forming dark terrain. Evidence cited includes smooth patches in lows, embayed craters, and small crater depletion [6-10]. Initial results from Galileo Regio and Marius Regio show that the albedo of dark terrain at high resolution is very heterogeneous and slope-related, with some brighter north-facing slopes perhaps due to sublimation and redeposition, and downslope movement revealing brighter material, with dark material moving into topographic lows. Impact craters have a wide range of degradation states and several processes operate to modify and infill craters including ejecta emplacement from adjacent large craters, mass wasting and downslope movement of material to fill crater floors, bright plains formation, and the formation of dark plains of possible volcanic origin. In Galileo Regio, many craters show evidence of regional tectonic fabric in their walls that is not evident in the surrounding intercrater plains, suggesting that deformation operated early in the history of the dark terrain but prior to the formation of the dark intercrater plains. Tectonic deformation is seen to heavily modify and distort some craters and intervening areas in Marius Regio, and dark smooth plains are not as abundant as in Galileo Regio although some are seen in the vicinity of a large degraded palimpsest. Viscous relaxation of larger craters is suggested by bowed crater floors; stereo data in Galileo Regio provides data to assess this quantitatively. High resolution Galileo images have emphasized the diversity of terrains and processes operating within and between dark terrain regions. Upcoming targets are designed to document other important components and further determine the diversity of dark terrain and the relative significance of these different processes.

(2) Nature, formation and evolution of furrows: Voyager images show variations in furrow morphology between different regions of dark terrain, and between different furrow "sets" in the same dark terrain [10,15]; individual tectonic troughs in dark terrain may have originated as graben or scarps and the origin of some has been attributed to basin ring formation [11-14] or to endogenic processes [7]. The Galileo Regio and Marius groove lane target areas provide data on the nature and age relationships between furrow sets. Galileo Regio stereo data show that the N-S trending System II furrows cross-cut and are younger than the NW-SE-trending System I furrow set. In addition, the younger furrows in general have relatively symmetrical topographic cross-sections more suggestive of graben than of asymmetric basin rings or ridges typical of many Valhalla basin rings on Callisto. System II furrows are deeper (up to 1.5 km deep) and have a more distinctive and linear raised rim (several hundred meters high) than do the older furrows. Galileo images also show details of how furrows clearly control subsequent structural development, with groove lanes tending to form parallel and normal to the major furrow systems.

(3) Nature of breakup of dark terrain: The initial stage of resurfacing and groove deformation in light terrain involved fragmentation of older dark terrain by large, throughgoing fracture zones [16-17]. The nature of this process and internal effects of fracturing on resulting small blocks are poorly understood because of a lack of very high resolution images showing comparable regions in successive stages of modification. Galileo high resolution images of several sites in and adjacent to Marius Regio show that groove lanes generally display parallel fractures and graben in adjacent dark terrain, particularly within about 10-50 km from the margin. These closely spaced fractures provide insight into the nature of the downfaulted terrain below the groove lanes and suggest that at least in part, subsequent deformation of the underlying fabric may control the formation of groove polygons. In addition, there is clearly a strong structural control on the orientation of groove lanes related to preexisting furrow trends.

(4) Emplacement of light material: In Voyager data, patches of smooth, ungrooved light material and confinement of light material by apparent fault scarps have been cited as evidence of emplacement in fluid form [11, 18-19]. In some places, smooth light material shows a feather edge on surrounding terrain whose appearance contrasts enough that it may be possible to see a flow front, and from its morphology infer rheology of ice-lava

[20]. In some cases, light material appears to have been emplaced as a very thin mantle on older, rough topography without infilling its low spots [17, 21] perhaps indicating explosive ice-volcanism. Galileo high resolution data showed little positive evidence for cryovolcanism (e.g., flow fronts, embayment, very smooth deposits, etc.) in the Uruk Sulcus area [2]; in fact these data revealed evidence of tectonic resurfacing as a major process. Evidence for local occurrences of relatively smooth bright plains have been observed in parts of Nippur Sulcus and in the transitional terrain in eastern Marius Regio, but lobate flow fronts and convincing embayment relationships have not yet been observed. If these smooth deposits represent cryovolcanic activity, their occurrence intermingled among grooves suggests that the lava was emplaced in a relatively fluid form and likely before or contemporaneous with groove formation. Areas suspected to represent pyroclastic mantling of dark terrain adjacent to bright terrain appear instead to be highly fractured and tectonically brightened. Subsequent targets will focus on additional areas of possible cryovolcanic activity.

(5) Formation of grooves: On the basis of Voyager data, grooves about 8 km wavelength were thought to have originated as graben, modified tension fractures, or ductile necking features [4,22-23]; Voyager images are insufficient in resolution to resolve this issue. Grooves sometimes exhibit morphologic differences between regions and these could arise from mass wasting, differences in strain rate or thickness of the lithosphere[19, 23], constructional ice-volcanism, or surface deformation due to ice-plutonism in underlying fractures [24]. Galileo data to date show no certain evidence for volcanism associated with groove formation, but do show that there are many more fractures associated with groove lanes than thought from Voyager resolution, that grooves are formed primarily by tectonic deformation, and that there are several different modes of tectonic deformation of grooves (graben, rotational tilt-block, and shear). Multiple observed wavelengths of deformation may be related to a ductile necking instability and brittle deformation of the lithosphere.

(6) Sequence of events during light terrain formation: From Voyager data, complicated stratigraphic relations of different light terrain morphologic features record a history of resurfacing and deformational processes. Voyager-based investigations [16, 17] all agree on the basic concept of breakup of older dark terrain into progressively smaller blocks, but disagree on critical details. Some [16] suggest that breakup preceded a later stage of resurfacing which somehow preserved the older, throughgoing grooves outlining the lithospheric blocks. Others [17] agree that a more complicated history must have occurred in which resurfacing and groove deformation were interspersed, and the oldest throughgoing grooves were later reactivated and occupied by younger tectonic features. The main reason for this divergence in views is that most of the critical morphologic details key to stratigraphic relations were at the resolution of the images. Galileo data of several bright terrain areas show minimal evidence for extensive cryovolcanic resurfacing of individual isolated polygons, particularly during the later stages of bright terrain evolution; some polygons that appear to be relatively smooth (and thus young and resurfaced) at Voyager resolution are instead, tectonically deformed but subdued older terrain (on the basis of both crater density and cross-cutting relationships). Tectonic resurfacing is seen to be a very important process late in the history of grooved terrain emplacement and is often accompanied by shear deformation, particularly along previous groove pairs and marginal grooves. Shear deformation is also important in the transition from dark to light terrain and the early evolution of bright terrain emplacement. Stratigraphic relationships established in Galileo high resolution data in Uruk Sulcus permits extrapolation to Voyager data of the rest of Uruk Sulcus and suggests that groove orientation and deformation style changed with time, with a rotation of extensional stresses from NW-SE to NE-SW with time. Future targets will permit similar sequences to be developed for other areas and compared globally.

References: 1] M. Carr et al., *JGR, 100*, 18935, 1995; 2] M. Belton et al., *Science, 274*, 377, 1996; 3] Q. Passey and E. Shoemaker, *Satellites of Jupiter*, 379, 1982; 4] E. Shoemaker et al., *ibid*, 435, 1982; 5] W. McKinnon and E. Parmentier, *Satellites*, 718, 1986; 6] A. Woronow et al., *Satellites of Jupiter*, 237, 1982; 7] R. Casacchia and R. Strom, *JGR, 89*, B419, 1984; 8] S. Croft and B. Goudreau, *LPSC 18*, 209, 1987; 9] S. Murchie et al., *Icarus, 81*, 271, 1989; 10] S. Murchie et al., *JGR, 95*, 10743, 1990; 11] B. Smith et al., *Science, 206*, 927, 1979; 12] W. McKinnon and H. Melosh, *Icarus, 44*, 454, 1980; 13] P. Schenk and W. McKinnon, *Icarus, 209*, 1987; 14] S. Murchie and J. Head, *JGR, 93*, 8795, 1988; 15] M. Zuber and E. Parmentier, *JGR, 89*, B429, 1984; 16] M. Golombek and M. Allison, *GRL, 8*, 1139, 1981; 17] S. Murchie et al., *JGR, 91*, E222, 1986; 18] B. Lucchitta, *Icarus, 44*, 481, 1980; 19] E. Parmentier et al., *Nature, 395*, 290, 1982; 20] M. Allison and S. Clifford, *JGR, 92*, 7865, 1987; 21] P. Helfenstein, *LPSC 18*, 333, 1986; 22] J. Fink and R. Fletcher, *NASA TM-84211*, 51, 1981; 23] S. Squyres, *Icarus, 52*, 545, 1982; 24] S. Croft et al., *Icarus, 73*, 279, 1988.