MATERIAL UNITS, STRUCTURES/LANDFORMS, AND STRATIGRAPHY FOR THE GLOBAL GEOLOGIC MAP OF GANYMEDE (1:15M). G. Wesley Patterson[1], James W. Head[2], Geoffrey C. Collins[3], Robert T. Pappalardo[4], Louise M. Prockter[1], and Baerbel K. Lucchitta[5], [1]Applied Physics Laboratory, Laurel, MD 20723, (Wes.Patterson@jhuapl.edu), [2]Brown University, Providence, RI, 02912, [3]Wheaton College, Norton, MA, 02766, [4]Jet Propulsion Laboratory, Pasadena, CA, 91109, [5]USGS, Flagstaff, AZ, 86001.

Introduction: In the coming year we will complete a global geological map of Ganymede that represents the most recent understanding of the satellite on the basis of Galileo mission results. This contribution builds on important previous accomplishments in the study of Ganymede utilizing Voyager data [e.g., 1-5] and incorporates the many new discoveries that were brought about by examination of Galileo data [e.g., 6-10]. Material units have been defined, structural landforms have been identified, and an approximate stratigraphy has been determined utilizing a global mosaic of the surface with a nominal resolution of 1 km/pixel assembled by the USGS. This mosaic incorporates the best available Voyager and Galileo regional coverage and high resolution imagery (100-200 m/pixel) of characteristic features and terrain types obtained by the Galileo spacecraft. This map has given us a more complete understanding of: 1) the major geological processes operating on Ganymede, 2) the characteristics of the geological units making up its surface, 3) the stratigraphic relationships of geological units and structures, and 4) the geological history inferred from these relationships. A summary of these efforts is provided here.

Material units: We recognize four fundamental geologic materials on Ganymede; dark, light, reticulate (**r**), and impact material [11,12]. Type localities for each unit have been identified. On the basis of our mapping, dark material on Ganymede has been subdivided into three units; cratered (**dc**), lineated (**dl**), and undivided (**d**), while light material has been subdivided into four units; grooved (**lg**), subdued (**ls**), irregular (**li**), and undivided (**l**). Impact material encompasses palimpsest, crater, and basin materials. Palimpsest material is further subdivided into four units; three of these are distinguished on the basis of their stratigraphic relationship with light material units (**p$_1$**, **p$_2$** and **pu**) and the fourth is an interior plains unit (**pi**). Five crater units – fresh (**c$_3$**), partially degraded (**c$_2$**), degraded (**c$_1$**), unclassified (**cu**), and ejecta (**ce**)- comprise the crater materials, and two units – rugged (**br**) and smooth (**bs**) - comprise the basin material.

Structures and Landforms: Several important structures and landforms on Ganymede have been identified and mapped (Fig. 1). These include; furrows, domes, grooves, secondary craters, depressions, and crater rays. Furrows are typically organized into vast multi-ringed systems and are the oldest recognizable structures on the surface, predating essentially all craters larger than 10 km in diameter [13]. Individual furrows (Fig. 1a) are characterized by linear to curvilinear troughs bounded by raised rims, which are generally bright. They are represented on the global map as lines drawn on dark material units. They extend from tens to hundreds of kilometers in length and are typically ~6 to 20 km wide, with generally flat or u-shaped floors and sharp raised rims [1,7]. Domes on Ganymede are features associated exclusively with the interiors of craters having diameters between ~60 km and ~175 km (Fig. 1b). They are typically circular in map view and occur within central pits. In cross-section they are steep-sided with flat-topped to concave profiles that can reach heights of up to ~1.5 km above surrounding materials [14]. Grooves (Fig. 1c) represent subparallel ridges and troughs observed within many light material units and their formation is attributed to extensional tectonism [1,6]. Secondary craters (Fig. 1d) are represented by fields of uniform small pits oriented radially to subradially and surrounding large fresh craters, partly degraded craters, palimpsests, and basin materials. Depressions (Fig. 1e) have been interpreted to represent caldera-like source vents for icy volcanism, with ~30 having been recognized from image data of Ganymede [10,15]. Finally, crater rays (Fig. 1f) have been mapped and represent the distinguishing characteristic between fresh and partly degraded craters.

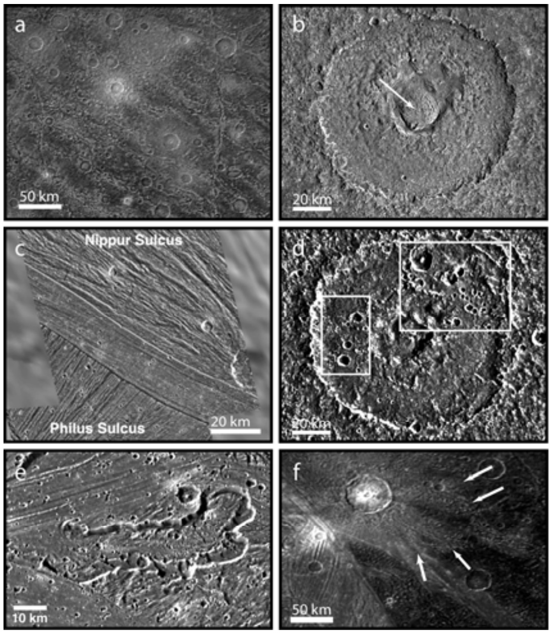

Fig. 1. Examples of structures and landforms represented on the global geologic map of Ganymede, including; (a) furrows,

(b) domes, (c) grooves, (d) secondary craters, (e) depressions, and (f) crater rays.

Stratigraphy: As part of our global mapping effort, we have identified ~4000 craters >10km in diameter across the surface of Ganymede. This dataset has enabled us to calculate crater densities (on a global-scale) for each of the material units we have defined (Table 1). It has also provided a valuable link to previous regional estimates of crater densities calculated for various material types utilizing counting areas 10 to 100 times smaller [e.g., 1,16].

Table 1.

	10 km[a]	20 km	30 km	Area (x 10^6 km^2)
Light				
grooved	39±2 (44±3)[b]	14±1 (14±2)	8±1	9.29 (5.71)
irregular	30±4 (20±5)	13±3 (5±2)	6±2	1.94 (0.992)
subdued	42±2 (39±3)	18±1 (15±2)	9±1	8.24 (4.90)
Dark				
cratered	85±2 (97±2)	32±1 (34±1)	15±1	21.9 (16.3)
lineated	67±8 (69±8)	19±4 (20±4)	8±3	1.06 (1.01)
Reticulate				
reticulate	39±12 (39±12)	18±8 (18±8)	4±4	0.28 (0.28)
Impact				
Palimpsest	61±7	23±4		1.37
Basin	19±5	11±4		0.80

[a] Number of craters ≥ the quoted diameter, normalized to 10^6 km^2.

[b] Numbers in parenthesis indicate values calculated from image data at resolutions ≤ 1.5 km/pixel.

These data confirm that dark cratered material is the oldest material on Ganymede and that light materials formed substantially later. Dark lineated material and reticulate terrain have crater densities on the higher end of light material units, suggesting they mark a transition into the formation of light materials. Palimpsests are older then light materials, dark lineated material, and reticulate terrain, but younger then dark cratered terrain. Finally, Gilgamesh basin appears to be younger then light materials.

Beyond crater statistics, the mapping of groove orientations within polygons of light material and the cross-cutting relationships of those polygons with respect to each other have given us insight into the time sequence and driving mechanism for their formation [17,18]. To determine a time-sequence of formation for light material, ~2000 light material polygons were run through a sorting algorithm [19,20]. The results suggested that four episodes (Fig. 2) of light material formation could describe the observed distribution of the orientations of grooves within polygons of light material. Using this distribution, and the fact that light material appears to form predominantly by extension [1,6,21], it was suggested that a strain history for light material formation could be determined [18]. This history was then compared to various driving mechanisms proposed to have led to the formation of light material and it was determined that stresses due to internal differentiation provided the best fit to the data.

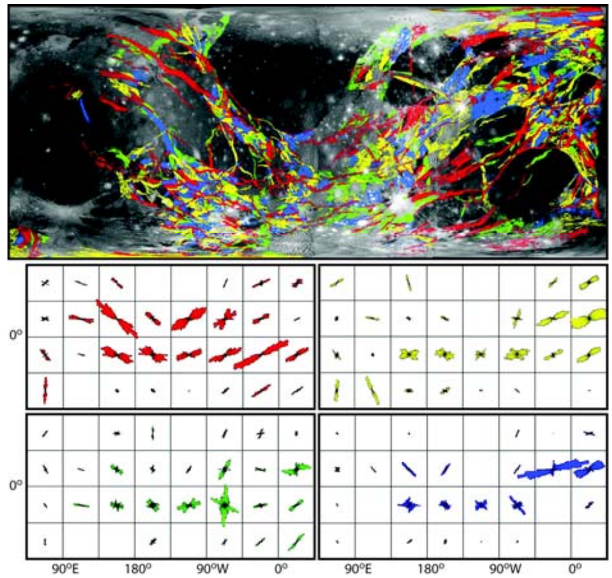

Fig. 2. Global image mosaic of Ganymede with 4 episodes of light material formation superposed (red, yellow, green, and blue). Variability of the orientations with latitude and longitude of groove sets within each episode are shown.

Summary: In compiling the first global geologic map of Ganymede, we have been able to integrate valuable insights garnered from the Galileo mission into extensive work done mapping quadrangles of the satellite's surface based on Voyager data [e.g., 3-5]. New map units have been described and some previously determined ones have been combined, important structures and landforms have been recognized and classified, and a global stratigraphy has been determined. Finally, based on these mapping efforts, a driving mechanism for the formation of light material has been proposed.

References: [1] Shoemaker et al., in The Satellites of Jupiter, 435-520, 1982; [2] McKinnon and Parmentier, in Satellites, 718-763, 1986; [3] J.E. Guest et al., USGS Map I-1934, 1988; [4] D.E. Wilhelms, USGS Map I-2242, 1997; [5] B.K. Lucchitta et al., USGS Map I-2289, 1992; [6] Pappalardo et al., Icarus, 135, 276-302, 1998; [7] Prockter et al., Icarus 135, 317-344, 1998; [8] Prockter et al., JGR 105, 22,519-22,540, 2000; [9] Oberst et al., Icarus 140, 283-293, 1999; [10] Schenk et al., Nature 410, 57-60, 2001; [11] Patterson et al., LPSC XXXVIII #1098, 2007; [12] Patterson et al., USGS Open-File Report 2007-1233, 2007; [13] Passey and Shoemaker, in The Satellites of Jupiter, 379-434, 1982; [14] Schenk et al., in Jupiter, 427-456, 2004; [15] Lucchitta, Icarus, 44, 481-501, 1980; [16] Murchie et al., Icarus 81, 271-297, 1989; [17] Collins, LPSC XXXVIII #1999, 2007; [18] Collins, LPSC XXXIX #2254, 2008; [19] Crawford and Pappalardo, Astrobiology, 2004; [20] Martin et al., LPSC XXXVII, 2006; [21] Collins et al., Icarus, 135, 345-359, 1998.