MORPHOLOGY OF BYBLUS SULCUS, GANYMEDE FROM GALILEO SSI DATA.

C. Thomas[1,2], J. W. Head[1], and the Galileo SSI team. [1] Dept. of Geological Sciences, Box 1846, Brown University, Providence, RI 02912, USA; [2] also at Lancaster University, Lancaster LA1 4YQ, England (c.thomas1@lancaster.ac.uk).

Introduction: Byblus Sulcus is a bright groove lane identified in Voyager 2 images, located at 39°N 201°W in northern Marius Regio on Ganymede. It was imaged at high resolution (86 m/pxl) and high sun angle on September 6th 1996, during the G2 orbit of the Galileo Orbiter. This region was targeted in order to provide high resolution images of an impact feature named Nergal with a distinctive dark/bright ejecta blanket - also in the imaged region is a roughly east-west trending groove lane named Akitu Sulcus. Another (near-terminator) image of north Marius Regio containing this area was taken at a 940 m/pxl resolution during the later G8 orbit to provide regional context for the G2 image; this also provides useful topographic information. This region was mapped previously by Murchie and Head [1] on a 1:5,000,000 scale using Voyager images as a base. They defined three geological units in this area - dark furrowed terrain (df) containing eastward-trending furrows, light grooved material (lg) consisting of high albedo sets of conspicuous grooves, and bright or partly degraded craters (c1,c2) [1]. A preliminary analysis of this area based only on G2 Galileo data presented by Head et al. [2] is expanded here.

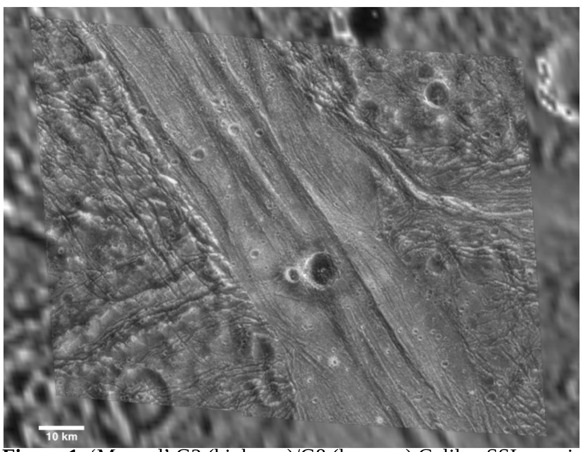

Figure 1: 'Merged' G2 (high sun)/G8 (low sun) Galileo SSI mosaic of the Byblus Sulcus region on Ganymede.

Data: For this analysis the G2 images were mosaicked, projected onto the G8 context image and reprojected as a Lambert equal area projection centred at 39°N 201°W. Layering both images over each other (see Figure 1) proved to be a very powerful yet simple aid to image interpretation - by rendering the G2 image partially transparent over the G8 image, it was possible to directly correlate albedo features in the high sun G2 image with topography observed in G8.

G8 Morphology: The overall shape of Byblus Sulcus is lenticular, thinning to the north and south and widest (~ 30 km across) in the area imaged at high resolution during G2. The southern apex of the sulcus ends in a deep crack that shallows and curves eastwards at its termination, and its albedo at this resolution is higher than that of the surrounding dark terrain. Ridges and scarps run parallel to but are not centred along the axis of the sulcus - these have a wavelength of approximately 10 km that can be readily observed in both G2 and G8 images using Fourier transform analysis [3]. This topography is especially visible in the northern half of Byblus (which includes the G2 image) - in the southern half the topography is more subdued, consisting of multiple shorter wavelength parallel ridges with comparatively lower relief. Nergal crater is distinctly visible in G8, but due to the low-sun imaging geometry no albedo differences between its environs and more distant bright terrain can be distinguished.

Two other small groove lanes trending roughly E-W and NE-SW are cut by Byblus Sulcus. Preliminary analysis suggests that they may be displaced by a 60 km sinistral shear across Byblus, supporting an observation noted by Murchie & Head [4]. Several other lineaments (e.g. furrows) along its length also appear displaced in this manner. These features are readily identifiable on either side of Byblus by their similar (and in the case of the groove lanes, unique) morphologies. This observation is investigated further in this study.

G2 Morphology: The G2 mosaic is divided here into three main areas based on the Voyager images - highly tectonised dark terrain in the west, the morphologically distinct Byblus Sulcus (trending N145E) in the central third of the image, and a second region of dark terrain in the east that contains the westernmost portion of Akitu Sulcus.

Western Dark Terrain (WDT): This region is characterised by a low albedo background surface interspersed with bright rounded higher-albedo hills several kilometres across, and two orthogonal sets of dark lineaments (fractures and troughs) that divide the terrain into polygonal units a few kilometres across. One set of these lineaments trends roughly parallel to the groove lane (N145-135E) and cross-cuts the other trend (N65E), which is itself sharply cut by Byblus Sulcus. Although the NW trend continues all the way along the image, the lineaments appear to be more densely packed in the northern half of the image nearer the sulcus, and some of the major lineaments curve in towards it near the centre of the image.

The N65E trend is centred around three large sub-parallel ridges separated by two troughs, with smaller scale sinuous dark and bright lineaments run roughly parallel and through them. The topographic relief is difficult to discern using the G2 image alone, and was distinguished using the G8 low-sun image. While these features can be separated at high resolution, at lower resolution they can be grouped as a single feature and were classed as such by Murchie et al. [5], who interpreted them as a single System I furrow.

Byblus Sulcus (BS): The central N145E band in the G2 image is comprised of sets of parallel or subparallel densely packed flat-topped and 'knobbly' ridges approximately 1-3 km wide and one kilometre high. Individual ridges frequently widen out or thin along their length, to the point of becoming wide plateaux up to 5 km across or small linear knobs a kilometre or so across. Like other groove lanes on Ganymede, at lower (i.e. G8, Voyager) resolutions Byblus is distinguishable from the surrounding dark terrain by its higher relative brightness. At G2 resolution however, a significant contributor to the brightness of the sulcus appears to be local features such as the bright ejecta blankets of small craters, high-albedo material on sunward facing slopes and ridges, and small-scale surface texture rather than the actual base albedo of the sulcus material itself which instead appears not too dissimilar to that of the dark terrain.

The overall trend of the ridges within Byblus is unidirectional, parallel to the axis of the sulcus; however, closer examination reveals that ridges are oriented along smaller curvilinear/arcuate subtrends that lie concordant to the main trend between extremes of N5-130E, with most lying between N145-150E. Of particular note is a lenticular region on the northeastern border of the sulcus in which ridges bend around a straight central axis that runs through its length and is parallel to the nearby Byblus/Eastern Dark Terrain boundary. The borders of several of these sub-trends frequently correspond to major topographic changes (usually west-facing scarps) running along the axis of the sulcus. In addition, these small-scale ridges are clearly superimposed on both the flat regions and the slopes of the large-scale G8 topograpy. Of particular note are two distinct broad high-relief ridges approximately ten kilometres apart that run along the strike of Byblus just east of its axis, that stand out visually only in the G8 image.

Eastern Dark Terrain (EDT): Tectonism is more complex in this part of the dark terrain - the 'furrow' visible in the Western Dark Terrain does not appear to correspond to any features visible in the east. A densely-packed set of dark lineaments (fractures) and bright lineaments (ridges) abuts against the northeastern border of Byblus near the lenticular region described previously. The orientation of these lineaments rotates from N145E (parallel to the Byblus trend) to N90E, and the area covered by them widens towards the central eastern part of the image; terrain is highly disrupted in this zone and some large craters near the Byblus are heavily tectonised. This region corresponds to Akitu Sulcus. To the north of this sulcus, a set of arcuate fractures defines a semicircular region that is comparatively fracture-free at G2 resolution.

Dark Terrain impact features: Craters in the dark terrain range in size from ~500 m to 12 km in diameter and can be found in varying states of degradation. The north-facing rims are generally the brightest parts of these craters (even though solar illumination is from the southeast with the sun 37° above the horizon), and ejecta are not generally obvious due to low albedo contrast. Dark terrain craters range from those with a morphologically fresh appearance and sharply defined bright rims to degraded craters with poorly defined circumferences and shallow bowl-shaped interiors (often with more recent craters superposed) and heavily tectonised craters modified by fracturing.

Bright Terrain impact features: The craters in Byblus Sulcus range from ~300 m to 8 km in diameter. All the visible craters are fresh, with sharp rims; there are no degraded or partially destroyed (and by implication 'old') craters visible in this area at all. The morphology of these small fresh craters strongly resemble those in the Dark Terrain - in both instances the crater outlines are generally asymmetrical with most having a pronounced triangular or square plan. Bright ejecta is also visible around some of the craters here.

The main features of note in Byblus Sulcus are the two craters in the centre of the G2 image surrounded by dark lobate structures and an irregular bright ejecta blanket beyond. No secondary craters have been unambiguously identified; either they never formed, are below the limit of resolution, or they have been removed or covered by some unrecognised process.

The larger crater (Nergal) is ~8 km in diameter with a polygonal rim, dark floor, and a broad cruciform central peak structure. The eastern rim is highly modified and appears to follow the trend of impinging lineaments in Byblus - it appears that it has collapsed eastwards into the sulcus and formed a wide (albeit short in radial extent - just over a kilometre in length) debris fan. Lineaments can also be seen continuing through the crater, modifying the eastern crater floor and central peak structure; these are not as apparent in the western part of the crater.

The smaller (unnamed) crater to its west is ~3 km in diameter with a circular bowl-shaped appearance (though it does have a small central peak). It is not modified in any way by the lineament structure in Byblus; indeed, a pronounced bright lineament stops at the outer boundary of the southeastern wall of this crater.

These craters are both surrounded by thick dark lobate structures that are in places outlined by what appears to be a brighter levee-like structure, probably emplaced as a consequence of the impacts; close examination suggests there may be multiple lobe sets, though it is not unambiguous which ones are associated with which creater.

Both craters are in turn surrounded by an asymmetric bright deposit that appears confined to the Bright Terrain only - the eastern border appears to follow the Byblus/EDT boundary. The outline of the deposit is highly irregular and does not correspond to that of the dark lobes immediately surrounding the craters - indeed, there is a thin triangular extension of this deposit extending northwards along one of the major G8 ridges in the eastern portion of Byblus. A small crater to the NW of Nergal may contribute in part to this ejecta blanket.

The lineaments in the underlying sulcus appear to continue through Nergal itself (and its lobate ejecta) but not through the unnamed smaller crater - however, the smaller crater is located in a smoother, comparatively lineament-free area that continues approximately 40 km either way along the strike of Byblus. Either the ridges in this area have been subdued somehow (perhaps by cryovolcanism) or they never formed here.

Fracture trends: Dark lineament (fracture) trends were measured in both the Western and Eastern Dark Terrains in the G2 image (these were not visible at the G8 resolution). The trends in each region are shown in Figure 2 below, with fractures binned at five-degree intervals and orientations measured clockwise (eastwards) from north.

The histograms suggest a marked difference in the orientation of fractures on either side of Byblus Sulcus. The WDT contains two distinctly separable sets of lineaments; one between N41-100E associated with the System I furrow and the other between N110-165E corresponding to the fractures parallel to Byblus. The EDT shows a different, more dispersed set of orientations that are not clearly divisible into two separate groups; however, both Dark Terrains appear to contain a preponderance of fractures oriented between N131-140E.

Conclusions and further work: The dissimilarity in dark lineament orientation trends, surface morphologies and textural character on either side of Byblus Sulcus can most easily be explained if one assumes that features on either side are not directly correlative as they stand. Furthermore, the similiarity between the orientations and morphologies of surface features displaced along Byblus suggests that the present configuration of the terrains may not be the original. Preliminary work suggests that this area may have been subject to shear; the appearance of this region today can be most simply explained by a 60 km displacement along a sinistral shear fault running approximately along the axis of Byblus.

There is still much work to be done to investigate this hypothesis fully - for example, the presence of shear accomodation zones in other parts of north Marius Regio has yet to be confirmed, although an area of interlinking lenticulate features and sinuous groove lanes in the dark terrain to the southeast of Byblus (also imaged by Galileo at 188m/pxl resolution) has been tentatively identified as a potential candidate area and is currently being investigated. It is also not yet clear how the shear could be accomodated within Byblus Sulcus itself, although the curvilinear and lenticular subtrends of the ridges within it may represent shear structures. Despite these reservations, the shear hypothesis most readily explains the apparent misalignment of several features on a regional (G8) scale and the disparity in lineament orientations and surface morphologies in the dark terrain on a local (G2) scale.

References: [1]. S. L. Murchie & J. W. Head (1989), Geological map of the Philus Sulcus quadrangle of Ganymede, USGS Misc. Geol. Investigation, Map I-1966; [2] J. W. Head *et al.* (1997) LPSC 28, 539-540; [3] J. G. Patel *et al.*, Wavelengths of Ganymede Grooved Terrain determined from Fourier Analysis of Galileo Images, LPSC 29, 1998; [4] S. L. Murchie & J. W. Head (1988), JGR **93**: pp. 8795-8824; [5] S. L. Murchie *et al.* (1990), JGR **95**: pp. 10743-10768.

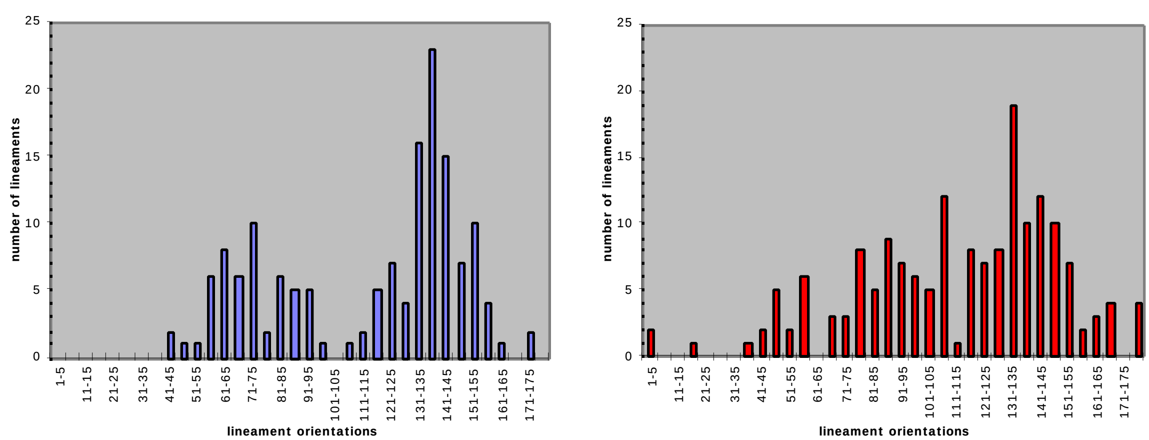

Figure 2: Dark Lineament Orientations in the Western (left) and Eastern (Right) Dark Terrains.