LANDING SITE CHARACTERISTICS FOR EUROPA 1: TOPOGRAPHY: P. Schenk,

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INTRODUCTION: Europa and its putative sub-surface ocean remain top priorities for planetary exploration [1]. Ongoing efforts to develop a robust program for the next phase of Europa exploration include serious consideration of a landed science package. Indeed, unambiguous determination of surface/subsurface chemistry and the internal structure of Europa's water and ice layers may require a surface package. The success of a Europa lander depends in large part on a firm understanding of the slope and roughness characteristics of the surface [e.g., 2]. In this report I survey the available topographic data and describe the slope characteristics of different geologic terrains. A major conclusion and a constraint on any Europa lander is that the surface is, with very few exceptions much steeper over more of its surface than on Mars.

TOPOGRAPHIC DATA: If a landed package is flown to Europa on the next mission to Jupiter (e.g., JIMO [3], then it must be designed based on available topographic data, all of which is derived from Galileo imaging. Galileo did not carry a laser altimeter, but elevation data in the form of digital elevation models (DEM) can be derived from stereo image analysis, from areal (or 2-D) photoclimonetry (shape-from-shading) of low-sun angle images, or from photoclinomtric elevation data controlled by stereo models. These data are limited to <20% of the surface due to the Galileo main antenna failure. Some of these data have been described elsewhere [e.g., 3-6]. Here I focus on those data suitable for high-resolution slope measurements of individual geologic features and terrains.

The stereo and areal photoclinometric techniques have been described in detail elsewhere [3-5]. Of chief interest here are the inherent errors and limits of each technique. Spatial resolution of the stereo technique is typically 4-5 times the horizontal resolution of the poorest resolution image in the original stereo pair. For Galileo, the images within stereo pairs are typically a factor of 3-7 different in resolution. Vertical resolution is dependent on stereo geometry parameters and is highly variable due to the nonsystematic Galileo imaging strategy.

Horizontal resolution of photoclinometry derived elevation data is identical to that of the original image (although the point-spread function of the Galileo imaging system will tend to blur and reduce slope estimates at sharp boundaries, this effects the result by no more than a few percent. Point-to-point vertical resolution is typically a few meters, depending on image resolution. Errors associated with photoclinometry come from a variety of sources [7] but for small scale features are most strongly dependent on the knowledge of the phase function used to model slope from apparent brightness. I use the combined lunar-lambertian function and estimate the photometric parameter as a function of phase angle. Arbitrarily varying the parameter by 20% results in only a few percent variation in slope estimate, although this effect is stronger as incidence angle decreases. Some errors in PC can accumulate along profile traces and produce longer-wavelength undulations in the DEM. In many cases, coincident stereo coverage (not susceptible to this effect) can be used to control and effectively eliminate this source of error.

SLOPES AND TERRAINS: A landing site on Europa is likely to be selected based on the desire to search for organic materials possibly brought to the surface geologically from Europa's putative ocean or from near the base of the floating ice shell. Candidate geologic terrains include gray bands, dark bands, and chaos, based on geologic inferences that they form as a result of geologic exchange of material between the surface and the interior.

Ridged plains make up a majority of the surface and may be the oldest terrain type. Ridges are typically several hundred to a few km across and only elevation data with spatial resolutions better than 100 m can be used. Ridged plains have RMS slopes (at 10 to 100 m length scales or baseline) of ~8 to 18° (Fig. 1). There are effectively no flat terrains between the closely packed ridges.

Dark bands are formed from lateral spreading of older ridged plains crust and replacement by newer dark materials [e.g., 8]. Gray bands appear to form by a similar mechanism but are inferred to be older [e.g., 8]. High resolution imaging indicates that dark bands are composed of closely spaced parallel ridge sets not unlike those within ridged plains. Although no high resolution topography exists, the similar ridge patterns suggest that slope characteristics may be similar to those of ridged plains. Gray bands are composed of flatter terrain, broken by knobs and occasional ridges. RMS slope values over grey bands (based on PC data only) confirm that they are significantly less steep than ridged plains: ~5° at 30-40 m length scales (Fig. 1). These may be the flattest terrains on Europa with dimensions suitable for 5-km landing ellipses.

Chaos consists of broken blocks of ridged plains surrounded by highly disrupted "matrix" material.

Chaos is thought to form by disruption of older ridged plains either as a result of localized melting of the icy shell, or through diapiric overturn within the icy shell [e.g., 8]. Matrix material is disorganized at kilometer to meter scales. Matrix units mapped at high resolution include the Conamara Chaos type locality and the unit southeast of Tyre [6]). RMS slopes within matrix and chaos generally range from 8 to 15° at 25 to 100 m length scales (Fig. 1).

Impact craters offer an alternative mechanism for excavating and exposing deeper materials onto the surface. Analysis of impact terrains is ongoing and suggests rugged relief. These data will be reported in detail in Houston

COMPARISON TO MARS: Mars RMS data for landing sites are limited but provide a valuable comparison to our Europa data. RMS slopes for the Viking, Pathfinder and MER landing sites are all between 2 and 5° over ~10 m lengths scales [9, 10]. Other sites considered but rejected for MER are steeper and more similar to Europa [10]. Analysis of slope distribution characteristics within individual terrains on Europa is also ongoing and will be reported in Houston. These will provide a more useful comparison to Mars' topographic characteristics and provide detailed constraints for lander design on Europa.

In addition to slope sharacteristics at decameter scales, Europa lander design is also concerned with roughness on the meter scale. The highest resolution topography data for Europa (~10 m/post) is a 2-frame E26 high resolution mosaic (Fig. 2). Although slopes here range from 5 to 15°, there are no indications in these data of rugged relief or boulder fields on individual ridge or block faces. Bouldery terrains are apparently limited to talus or debris deposits on the margins of chaos blocks. In the absence of high resolution altimetry data, macroscopic roughness estimates can be gleaned only from photometric analysis of the surface from the superior Galileo data set. Such analyses are ongoing at other institutes.

Galileo data are necessarily restricted both in horizontal resolution and in the degree to which they fully characterize different terrain types. Topographic data do not exist for a number of geologically interesting sites, and no data exist at the meter scale. A Jupiter orbiter equipped with both a dedicated stereo camera and a laser altimeter and placed in a phasing orbit would address most if not all of these concerns, mapping Europa at staggered longitudes and providing near global topographic coverage, anchored by precision altimetry. Global coverage, currently unavailable, would also allow investigators to select the youngest and most geologically interesting landing site prior to final lander design or launch.

[1] NRC Decadal Survey of Solar System Exploration, 2002. [2] Shirley, J, this meeting, 2005. [3] Report of the NASA Science Definition Team for the Jupiter Icy Moons Orbiter, 2004. [4] Schenk, P., Nature, 417, 419, 2002 [5] Schenk, P., and D. Williams, GRL, 31, in press, 2004 [6] Schenk, P., and R. Pappalardo, GRL, 31, L16703, 2004. [7] Jankowski D, and W. Squyres, JGR, 96, 20907, 1991. [8] Greeley, R., et al., Geology of Europa, in *Jupiter*, Cambridge Press, 2004. [9] Beyer, R, A McEwen, and R. Kirk, JGR, 108, ROV 26-1, 2003. [10] Kirk, et al., JGR, 108, ROV 29-1, 2003.

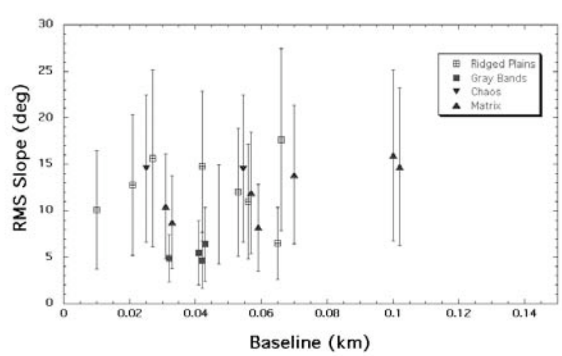

Figure 1. RMS slope values for selected terrains on Europa.

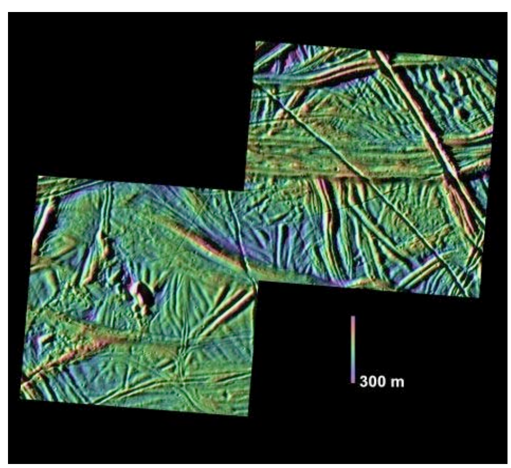

Figure 2. Highest resolution topographic data for Europa. E26 mosaic has been color-colded to show relief.