PRECISION AND ACCURACY OF TOPOGRAPHY MEASUREMENTS ON EUROPA. R. Greenberg[1], T.A. Hurford[2], M.A. Foley[3], and K. Varland[4], [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, [2]Planetary Geodynamics Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD 20771, [3]Dickinson College, Dept. of Physics and Astronomy, Carlisle, PA 17013, [4]Applied Mathematics, University of Arizona, Tucson, AZ 85721

Introduction: Determination of the topography of Europa's surface can in principle provide important information on the character of the icy crust and the processes that have shaped it. Unfortunately, the limited available imaging of Europa severely constrains the extent and precision of topographic mapping. Stereographic analysis is only possible at a few locales that have the required multiple image coverage, and photoclinometry depends on numerous assumptions regarding the optical properties of the surface. Qualitative examination of images can give an impression of topography, based on a combination of implicit assumptions about (a) the relationship between shading and slope and (b) analogies with similar recognized landforms. However, the quantitative limitations must be recognized, especially where accurate elevation information is critical to an interpretation. An example is the interpretation of chaotic terrain.

Many small patches of chaotic terrain on Europa appear to be bulged upward, which has contributed to qualitative impressions that chaos might represent "cryovolcanic" [e.g. 1] and/or convective upwelling [2]. However, the oceanic melt-through model for chaos formation explains the bulged appearance differently as simply the topography expected after refreezing and buoyant equilibrium [3,4]. An observational test to discriminate between these models was proposed in [3], based on whether or not the up-bulged chaos is higher than the typical tectonic terrain in the region (for up-welling) or only higher than its immediate moat-like surroundings (melt-through and refreezing). Several authors have taken up this challenge, presenting topographic maps to refute the melt-through model by showing high elevations for chaos [5,6].

For example, near Tyre Macula where high-resolution stereo is available, topographic maps and profiles have been invoked as a refutation of the melt-through model [5,6]. However, details on the methods (based on combinations of stereo images and photoclinometry) have been sketchy, and without quantitative discussion of uncertainties. Any results based on topography should not be accepted unless the methods involved have been subjected to rigorous and transparent quantitative evaluation. Here we consider the accuracy of some published results and some of the effects that can limit the precision of elevation measurements by both stereo and photoclinometry.

Stereography: The topographic study in [5] was presented as a "challenge" to the melt-through model. The case is made most strongly in the topographic map (Fig. 4a in [5]) of the area southeast of Tyre derived using stereo based on two high-resolution images. The profiles CD and EF across this area (Fig. 4b in [5]) include bars marking what is identified as chaos, and these areas are indicated as being hundreds of meters above the surrounding terrain.

However, we have performed a stereo analysis of the same region and find that most of the chaotic terrain at this location is actually lower, not higher, than the surrounding tectonic terrain. The same result is evident from direct stereo viewing of the image pairs (see, for example, the 3D red-blue stereo product PIA01654 on the JPL Photojournal). Moreover, some of the highest terrain identified in [5] as chaos is actually not chaos. Rather, it is the tectonic terrain surrounding the chaos. Thus the actual topography in this area is consistent with the melt-through model, rather than "challenging" it.

The vertical precision reported by [5] for their map is 8 m. However, our study of the geometry of the images used in the stereo analysis shows that an 8 m elevation difference would correspond to only 1/4 pixel displacement between the two images. In principle, sub-pixel precision could be obtained by averaging the displacement of a multi-pixel area from one image to the other, but that is only possible if appropriate areas of fairly constant elevation are identified. The character of chaotic terrain, especially the example in question, interspersed with numerous small high rafts, precludes such averaging. In this terrain, vertical precision of ~10 m is implausible. In fact, the presence of the rafts may account for the artificially high reported elevation of the chaos if the rafts were preferentially chosen as stereo tie points.

Systematic and random errors in that analysis are probably greater than any reported differences between elevations of chaotic and tectonic terrain. Given the problems in the mapping at this locale, caution is appropriate in interpreting maps of other locations produced by the same approach as [5], whether on Europa or other icy satellites.

Our own stereo analysis shows that (relative to the surrounding terrain) the chaotic terrain is about 150 m lower than plotted in [5]. However, some rafts protrude upward from the matrix of the chaotic terrain by as much as 150 m. The map presented in [6] gives results similar to ours. These results show that the matrix (between the large rafts) of the chaos in question is in fact lower than much of the surrounding tectonic terrain, not higher.

Despite the ~150 m discrepancy between the elevations reported in [6] and the incorrect elevations reported in [5], those results are described in [6] as being “in remarkably good agreement”. In fact those results differ by many times the reported precision of the measurements. Despite the fact that the elevations in [6] show the chaos to be lower than the surrounding terrain, it was taken as evidence for diapiric upwelling. In fact, the topographic study in [6] (as well our own stereo evaluation and direct 3D stereo viewing) shows no systematic elevation of chaotic terrain and is perfectly consistent with the melt-through model.

An additional consideration is that the topography in this area is likely affected by other things at least as important as the chaotic/tectonic terrain dichotomy. The context is important: The area is very close to Tyre, a major impact feature, which may have had important effects. Also, the east-west crack running through the area seems to be along a rise, showing that topography may be dominated by tectonics, perhaps related to the Tyre impact. In any case, so much diverse geological activity has occurred in this area that no clear systematic elevation difference between chaos and surrounding terrain can be inferred.

Photoclinometry: In a separate study, we have considered possible systematic errors that might affect topographic analysis by photoclinometry. Potential sources of error have long been recognized [e.g. 1], including the possible influence of albedo variations that could be interpreted as slope effects. That source of error is particularly important in considering topography of chaotic terrain relative to tectonic terrain, because surface darkening is common in both the matrix material of chaotic terrain and in halos that surround the chaos.

Another potential source of error is in sub-pixel scale surface roughness. We have considered various hypothetical scattering functions and sub-pixel slope variations. The subpixel roughness can introduce significant changes in brightness, and hence errors in inferred slope. For example, using a lunar-Lambert photometric function [7], with a 90% Lambertian component, which is plausible for Europa, we considered a pixel within which the average surface slope is 5%. We adopted a viewing geometry for this case similar to one of the high resolution images of the Tyre region discussed above. If, within the range of that pixel, the actual slopes were half 15% and half about 5% in the opposite sense, so as to give the net slope of 5%, the surface would appear significantly darker than with a smooth 5% slope. That darkening would correspond to an error in the inferred slope of about 10m per km. If the “roughness” were such that half the area within the pixel had a slope of 30%, then the error in slope would be 50m per km.

The combination of the various sources of uncertainties, including the photometric function, albedo variations, and sub-pixel topography and roughness introduces significant potential errors in topography determination by photoclinometry. Recognition of such uncertainty (as in for example [1]) is an important part of any interpretation of inferred topography.

Interpretive results based on topography should be accepted only if the methods involved have been subjected to rigorous and transparent quantitative evaluation. Accordingly, to paraphrase Mark Twain, reports of the death of the melt-through model for chaotic terrain on Europa have been greatly exaggerated.

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