THE CROP CIRCLES OF EUROPA: P. Schenk, Lunar and Planetary Institute, Houston, TX 77058 (schenk@lpi.usra.edu)

INTRODUCTION: During its rapid flyby of Europa in 1979, Voyager observed an enigmatic narrow arcuate depression near the terminator. Although Galileo failed to achieve one of its prime mission objectives, near-global coverage of the Galilean satellites at sub-kilometer scales, several terminator observations were acquired at dispersed longitudes and several additional arcuate depressions were observed. These limit morphologic mapping to 5 narrow longitudinal bands. With precision registration of all Galileo imaging now complete, a partial global map of these features is now possible.

THE CIRCLES: Three incomplete arcuate depressions or troughs have been identified, as well as a number of smaller associated, or secondary, basins (Fig. 1). The main troughs are roughly 25-40 km across and 500 or more km long. These features form two antipodally arranged 'circles' on the surface of Europa (Fig. 2). The best observed circle consists of two segments; one south of the equator at longitudes 145-165° W (Fig. 1) and the other north of the equator at longitudes 75-85° W. The estimated center of this circle (dividing the trace of each arc into 100 km long segments and using a least-squares fit [1]) is 120° W, 10° N. I refer to this as Circle 120.

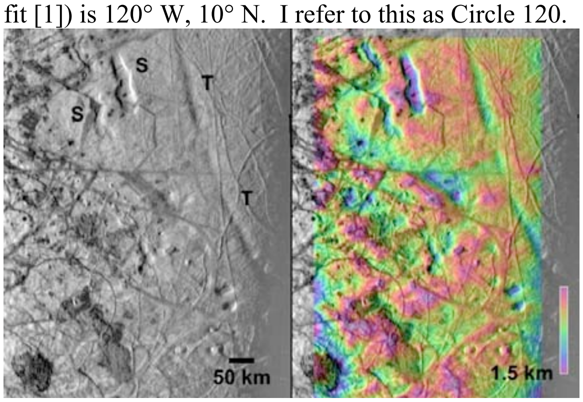

Figure 1. Image (left) and topographic map (right) of troughs (T) and secondary depressions (S) on Europa.

Only one major arc (at longitude 340° W from 0° to 12° N) was observed at the opposing circle due to restricted imaging and a center could not be reliably estimated for it directly due to its short length. When combined with Circle 120, however, the best-fit center remained at 120° W, 10° N (with the antipode at 300° W, 10° S), confirming that the two circles are indeed directly antipodal to each other. I refer to this as Circle 300. The average angular distance of the circles from the center is 43.3° ±0.3° for Circle 120, and 40.1° ±0.1° for Circle 300, indicating that these are indeed astonishingly circular features.

Several topographic basins lie in close proximity to the two circles described above. These are arcuate to amoeboid in shape, although all are elongated parallel to the neighboring circle arc. They are ~ 20-50 km across but only 100-300 km long and are found dispersed in widely separated sections of the circle circumferences. In several instances they occur in sets of 2-3 parallel basins spaced <100 km apart. Secondary basins are located at distances of 48 to 52° from their respective circle centers, roughly 100-200 km from the main circle arcs and always on the side outward from the relevant circle center (Fig. 2).

Three secondary basin were observed at better than 1 km resolution. Two (at 28°S, 175°W) (Fig. 1), were observed at 230 m/pixel; the other (at 35N, 90W) was observed at 32 m/pixel. No evidence of surface deformation, other than the topographic depression, was observed. Surface ridges and albedo features are uninterrupted. There is no evidence of faulting or resurfacing associated with these depressions, except that two of these depressions are bordered by relatively steep sides suggesting down-dropped graben. No structural control is evident in the main circle troughs, all of which are characterized by broad long-wavelength topography.

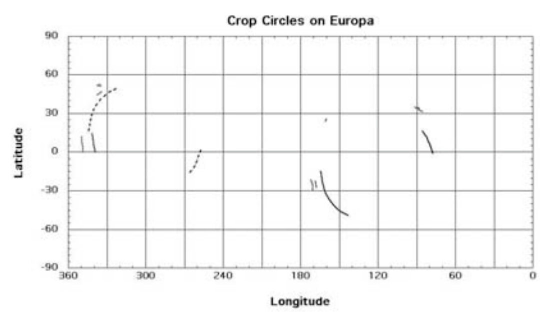

Figure 2. Location of circular troughs and depressions on Europa. Dashed line represents antipodal mirror "image" of troughs in the leading hemisphere transposed onto trailing hemisphere. Short segments are secondary depressions neighboring main arc segments.

TOPOGRAPHY: Although all the features described are clearly depressions (and are among the most prominent topographic features given their visibility 10's of degrees from the local terminator), topographic details are scarce. Stereo observations were obtained at only one point along Circle 120, and none of Circle 300. Photoclinometry (PC) is available for all circle and secondary basin segments. Both stereo and PC indicate that the arcuate circle segments are 300-500 m across. Stereo and PC show that two of the secondary basins are at least 1 km deep, and one may be as deep as 1.5 km (Fig. 1a). These are the deepest known features on Europa.

ORIGINS: Despite limited mapping coverage, there are several peculiar and ultimately diagnostic characteristics of these circular features. Each of the two "circles" is only partially developed. Circle 120, the best characterized, is only developed in opposing quadrants (i.e., the northeast and southwest quadrants; Fig. 2). Although a set of secondary basins is apparent in the northwest quadrant, no circle segment or arc is visible there or in the southeast quadrant despite similar imaging observations in the southern and northern hemispheres. The northern- and southern-most extents of Circle 120 were not observed. Geologic control of circle formation is uncertain due to the extremely limited imaging coverage, but Circle 120 occurs in both mottled terrain and ridged plains. Secondary basins form sets of depressions outside each ring. These depressions are 2-3 times deeper than the main rings but are less extensively developed azimuthally. None of these features appears to be related to resurfacing or other deformation other than down-dropping or warping of the surface. With the possible exception of linear depressions near Tyre, no other arcs are found in available low-sun imagery, covering ~35% of the surface. This suggests that the troughs are very young and older troughs relax away rapidly or that they are a relatively unique event in Europan history.

STRESS AND STRAIN: The depressed topography of these features indicates they are most likely due to extensional deformation of Europa's icy shell. Two mechanisms are considered. The first is subsidence due to a load. As there is no evidence for surface deposits, I infer that any loading must be within or at the base of the ice shell, and must be denser than the bulk shell, possibly diapirism along the trace of the troughs. More likely, the ice shell has been thinned in a ductile manner, without associated extensional faulting (except in some of the secondary basins). Thinning of a floating ice shell should lead to isostatic downwarping. The 1-1.5 km deep secondary depressions clearly indicate that the ice shell is not thin. A floating ice shell 2-3 km thin is not expected to survive thinning of such magnitude intact. Isostatic modeling [6] suggests that 1-1.5 km deep basins in undisturbed crust are not stable unless the shell is at least 10-14 km thick.

The antipodal circular arrangement of these circles and their associated secondary basins indicates a global external stress field. Of the three considered plausible for Europa: diurnal and/or long-term tidal deformation [2], nonsynchronous rotation [3], and polar wander [4, 5], I find reasonable matches of feature traces to principle stress directions for the first two models (Fig. 3).

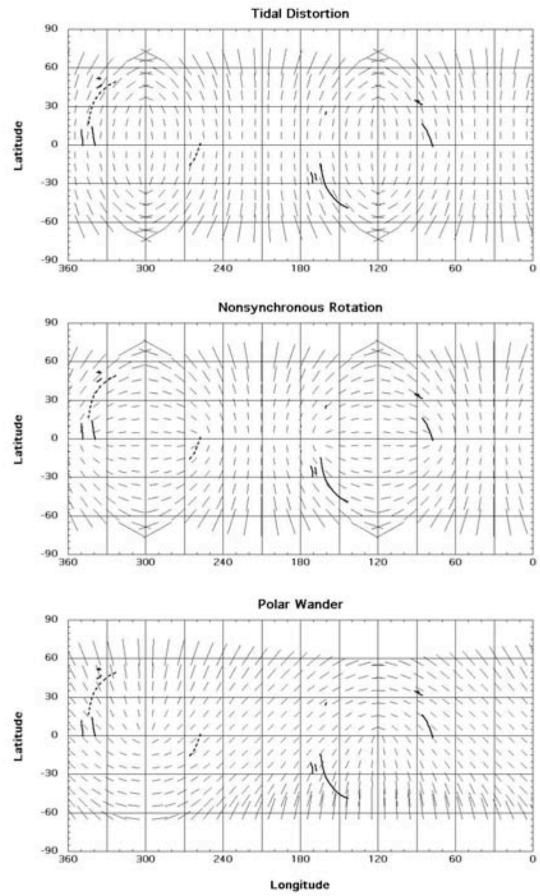

Figure 3. Comparison of circular troughs and depressions on Europa to stress trajectories for the major global stress fields. See text for explanation.

The matches to diurnal tidal and nonsynchronous stress fields are not exact, however, as the stress fields are not perfect circles at the locations of any of the circle structures (Fig. 3). In other words, the observed circles are too perfect. Also, in each case the observed circles must be offset in longitude to match current stress field locations, 60° west for tidal distrotion, and ~14.5° west for nonsynchronous rotation. The 10° offset of the circle centers from the equator is a curiosity but may be evidence for a modest amount of polar wander. Although a match to polar wander stress trajectories may be possible, it would require at least 40° of rotation about the tidal axis, coupled with 30° eastward migration of the shell to explain the observed pattern.

[1] Schenk P. & W. McKinnon, Icarus, 72, 209-234, 1987. [2] Helfenstein P. & E.M. Parmentier, Icarus, 53, 415-430, 1983. [3] Helfenstein P. & E.M. Parmentier, Icarus, 61, 175-184, 1985. [4] Ojakangas G. & D. Stevenson, Icarus, 81, 242-270, 1989. [5] Leith A. & W. McKinnon, Icarus, 120, 387-398, 1996. [6] Schenk P., & W. McKinnon, in prep., 2005.