THE SPACING DISTANCES OF CHAOS AND LENTICULAE ON EUROPA.

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Introduction: Chaos features on Europa are large, irregularly shaped regions of surface disruption containing a hummocky matrix material and blocks with linear-texture [1, 2]. Lenticulae are subcircular features generally 5 -10 km in diameter and divided into three types [2, 3]. Domes: upwarped features that do not disrupt the pre-existing terrain. Spots: smooth, low albedo areas that subdue pre-existing terrain. Pits: have a chaos-like matrix material and are thus called micro-chaos. The models of lenticulae and chaos formation have dissimilar implications for the thickness of Europa's ice-shell: the melt-through model requires a thin ice shell, no more than several km, atop an ocean and chaos is created by localized melting of the ice shell [4]; the diapirism model entails a thicker ice shell, 10 – 25 km [5], with a brittle lid overlying a ductile convecting layer that produces diapirs, which create lenticulae [3]. The surface merging of lenticulae or subsurface merging of plumes can create chaos [6]. The melt-through model states that lenticulae and chaos should be randomly spaced apart while the diapiric model predicts that features should be regularly spaced apart with a dominant spacing. Thus analysis of the spacing distribution of lenticulae and chaos may constrain the possible processes at work in the formation of these features and the thickness of the Europan ice shell.

Method: We selected several near-equatorial regions for study. First, we mapped the boundary of each feature containing chaos materials and labeled the feature according to its morphology. Then we located the center of each feature and measured the distance in pixels from that point to the center point of each of the nearest 6 neighbors to that feature. We averaged the spacing distances in pixels for each feature and then converted this mean to kilometers by considering the image resolution. The error in our identification of the center of each feature is minor, ~ 1 km. We recognize some minor uncertainty introduced by measuring the spacing distances of features that are near the boundary of an image, as its nearest neighbors may be outside the image and thus not visible.

Analysis: Table 1 records the specific data for the micro-chaos lenticulae and chaos spacing within each of the studied regions. The spacing distributions for the combined dataset (Fig. 1) and the individual studied regions (like the size frequency distributions [7]), are asymmetric and exhibit a peak indicting a predominance of data within a small range of spacing distances. The dominant range of spacing of features containing chaos materials is 16 - 36 km. The peaks in the spacing distributions for micro-chaos and chaos for the studied regions are noted in Table 1. Analysis of the statistics indicates that the mean, median, and mode relate to the peaks in the spacing distributions and are smallest for E15RegMap02, E4DrkMat02, E11Morphy01, and E6DrkLin01; intermediate in the E17RegMap01; and greatest in the E14Wedges01 and E11RegMap01.

It has been suggested that mapping of chaos regions may be resolution dependent such that many small features clearly seen in high-resolution images are not observable in regional map resolution images [4, 8]. Small, unmeasured features appearing in high-res images would lie between micro-chaos and chaos that were measured in reg-map images. If this were the case, the spacing distribution, ranges, and statistics should be notably smaller for the high-res observations than for the studied regional maps. The E11Morphy01 observation is adjacent to the studied E15RegMap02 segment and thus these regions are likely to have similar feature spacing distances if there are no resolution effects in the mapping. Indeed the statistics of E11Morphy01 are exceptionally similar to the E15RegMap02 statistics and their spacing distributions in are also similar in shape (Fig. 1). Additionally, E15RegMap02 has a smaller minimum spacing measured than E11Morphy01. Based on the results, we suggest the effects of mapping at reg-map and high-resolutions are thus negligible and our mapping is not neglecting a great quantity of small features in regional map resolution images.

In the studied regions we find that features classified as individual lenticulae based on morphology are generally spaced 15 – 23 km apart. For those individual lenticulae which may merge to make chaos the minimum spacing distances in the studied regions can be interpreted to be greater than the maximum distances for coalescence to occur.

Discussion: The models for lenticulae and chaos formation [3, 4] can be evaluated based on the spacing of micro-chaos and chaos on Europa. The whole-shell melt-through model dictates a continuum of spacing distances [4]; this is not observed. A defined peak in the spacing distribution is found in all of the regions studied and in the combined histogram. In a diapiric model the spacing of features containing chaos materials is determined by the properties of the convecting layer and thus a dominant spacing is predicted, consistent with the observations of a dominant spacing range of 16 – 36 km.

We find that the spacing in regions adjacent to large chaos features can be > 10 km less than the spacing in regions that are not adjacent to a large chaos feature. The authors of [9] suggest that lenticulae spacing should decrease around large chaos regions in a melt-through model because these small features are spin-off features from a main column of rising water. However, this model cannot explain the occurrence of small, dominantly spaced lenticulae far from a large chaos region. Also, the spacing of lenticulae does not always decrease surrounding a chaos region, such as those neighboring Conamara Chaos (E6DrkLin01). The variation in spacing around chaos regions is most consistent with a diapiric model where the merging of lenticulae, or subsurface merging of plume heads, will lead to decreased spacing; this is observed terrestrially in the salt canopy of the Great Kavir [10].

Chaos and lenticulae are generally the youngest features within the studied regions and are generally 4 – 8 km in diameter [11]; thus this size range of micro-chaos lenticulae and chaos is the size at which features are preferentially produced at and is analogous to a production population in cratering statistics. In a diapiric model, the minimum mean spacing distances of morphologically individual lenticulae, 15 - 23 km, reflects the production spacing of individual diapirs that are not affected by merging of lenticulae or plume heads. These results suggest that Europa's convecting sublayer should be ~7 – 10 km thick, approximately half the spacing distance [2, 12].

Conclusions: The spacing distribution of lenticulae and chaos has a dominant range of 16 – 36 km and suggests that Europa's convecting layer is ~ 7 – 18 km thick and thus the whole ice shell (convecting asthenosphere and brittle lithosphere) must be larger than 7 km thick. A plausible scenario is that a relatively thin ice shell with a thin lithosphere and asthenosphere was dominated by tectonism forming lineae and conductively thickened, initiating convection. Solid-state convection within the asthenosphere gave rise to plumes of similar size spacing and size. Local variations in heat input, shell thickness, or composition could allow merging of lenticulae to create chaos.

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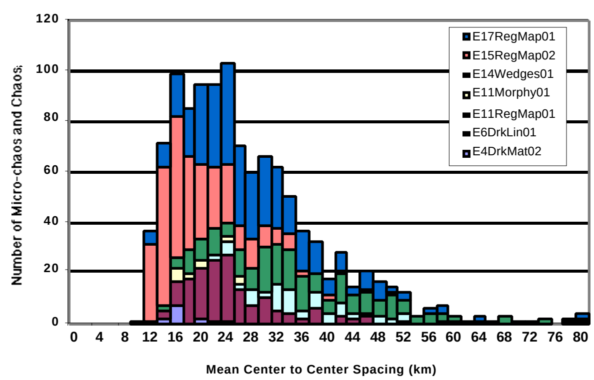

Figure 1. Spacing distribution of micro-chaos lenticulae and chaos within the studied regions of Europa.

Data	E4DrkMat02	E6DrkLin01	E11RegMap01	E17RegMap01*	E14Wedges01	E15RegMap02	E11Morphy01
Center Coords	(6°, 327°)	(10°, 271°)	(11°, 237°)	(15°, 210°)	(-10°, 180°)	(15°, 89°)	(35°, 87°)
Res (m/pxl)	25	180	220	225	230	230	30
Area (km^2)	1,586	91,920	66,500	269,500	716,300	420,100	2,135
Solar Angle	75°	83°	81°	74° - 81°	39° - 61°	74° - 82°	80°
Phase Angle	97°	39°	58°	71°	74°	100°	61°
Reprojection	orthographic	orthographic	transmerc	transmerc	orthographic	transmerc	orthographic
Image #s	3746854:03, 16, 29, 42, 55	3839137:00, 13, 26, 39, 52, 65	4206192:00, 13, 26, 39	466664:152, 165, 178, 200, 213, 226, 239, 252, 552, 565, 78, 600	440955:165, 178, 200, 213, 226, 239, 265, 278, 300	449974:200, 213, 226, 252, 265, 278, 300, 313, 326, 339	420626:700, 713, 726, 739, 752, 765, 778, 800

Table 1. Data and spacing distribution results for the studied regions. Res = image resolution. Transmerc = transverse mercator projection of the image mosaic. Image numbers are assigned by the Galileo Solid State Imaging experiment; all numbers begin s0 . . . .