CHAOS AND LENTICULAE ON EUROPA: STRUCTURE, MORPHOLOGY AND COMPARATIVE ANALYSIS

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Introduction: Based on Voyager imaging of Jupiter's moon Europa, Lucchita and Soderblom [1] classified the surface of this icy satellite into two major terrain types: plains and mottled terrain. Mottled terrain was defined as consisting of isolated small spots, hummocky topography, and sometimes broken-up lineae. One of the primary goals of the Galileo mission was to determine the origin and particular characteristics of mottled terrain. Recent Galileo images of Europa reveal areas of mottled terrain that are typified by an abundance of ovoidal features ranging from 5 to 20 km in diameter known as lenticulae [2] and larger disrupted features comprised of blocky material and hummocky matrix described as chaos [3,6]. Lenticulae have been divided into three major classes [4,5]: domes (upraised domical features which commonly do not affect the texture of pre-existing terrain), spots (smooth low albedo areas which subdue or conceal pre-existing terrain), and pits (lenticulae that have disrupted the pre-existing terrain and sometimes contain a chaos-like matrix material). A diapiric origin for lenticulae has been suggested by Pappalardo et al. [2]. The first recognized chaos region on Europa was Conamara Chaos (8˚N, 274˚W), imaged at 180 meters/pixel. Carr et al. [3] describes it as an irregularly shaped region with a discrete inward facing cliff-like boundary. Images of Conamara Chaos obtained during the Galileo Europa Mission at 54 m/pixel have allowed us to discern the two major terrain units comprising chaos: fragmented and dislocated polygonal blocks of background plains and a hummocky matrix of finer textured material [6,7]. Carr et al. suggested that chaos formed through a thermal upwelling [3]. We suggested that chaos may originate by coalescence of the surface effects of diapirs [6].

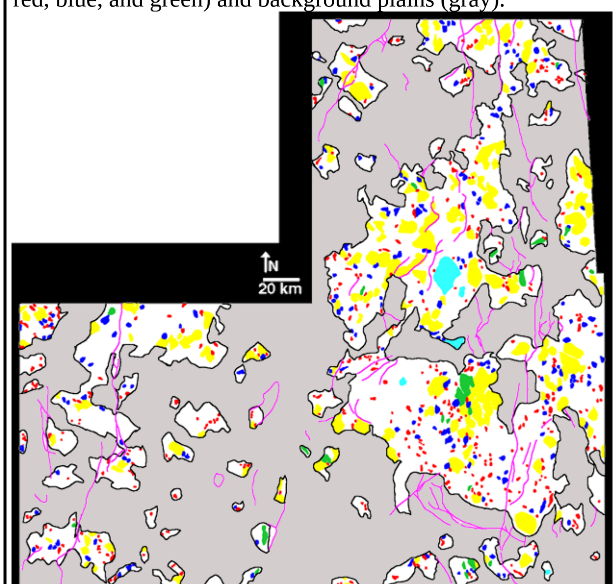
In this analysis, we address the questions: 1) what range of morphology characterizes the internal texture of chaos, and 2) is there a relationship between chaos internal texture and the micro-chaos within pits? The answers to these questions will help to constrain possible mechanisms for the origin of chaos.

What range of morphology characterizes the internal texture of chaos? The 54 m/pixel high resolution imaging of Conamara Chaos allows us to classify the individual units which comprise chaos: linear-textured polygons and matrix material. Linear-textured polygons (yellow) are angular fragments exhibiting recognizable linear textures (ridges, troughs, and bands) typical of background plains. The matrix can then be subdivided into angular polygons, micro-polygonal blocks, peaks, and hummocky matrix. These subunits are smaller in scale and differ in texture from linear-textured polygons, and/or are more affected by the hummocky material. Angular polygons (green) are steep-sided angular fragments of linear textured polygons with a steep tilt towards one side and a high cliff on the opposite side; these appear as if they may have been tilted relative to the plane of the Europan surface. Micro-polygons (blue) are smaller plate-like structures that show very faint evidence of linear texture, appear highly degraded, and are sometimes at a lower topographic elevation that the linear-textured polygons. Peaks (red) are individual ovoidal features usually less than 2 km across; these show very little or no linear texture and tend to be isolated peaks standing above the topographic level of the matrix, sometimes appearing to stand higher than the linear-textured polygon margins. Hummocky material (white) is a rough textured surface that is distributed between other matrix units and includes jumbled surface blocks from ~1 km in diameter down to the resolution limit of the image, ~200 m. We have found most or all of these units present in the 3 regions that we have studied.

We performed a reconstruction of the linear-textured polygons within Conamara Chaos to determine the movement and nature of blocks [6,7]. We found that linear textured polygons account for 40% of the chaos region; thus implying the destruction, removal, and/or heavy modification of more than half of the pre-existing terrain.

Is there a relationship between chaos texture and the micro-chaos within lenticulae? To address this question, we selected an area of Europa which exhibits both micro-chaos within pits and also chaos texture. The Galileo nominal mission obtained images (E11 Regional Map) of an area of mottled terrain centered at (5˚S, 237˚W) with a resolution of 220 meters/pixel. We applied our chaos subunit classification scheme to the structure and morphology of micro-chaos found in some lenticulae. We asked the questions: what are the similarities and differences in morphology and scale, and what can this reveal about modes of formation and the possible relationship between lenticulae and chaos? We also mapped structural features, such as troughs, domes, and escarpments, to study their possible relationships to chaos features. We located and mapped 61 features containing materials that fit the definition of chaos/micro-chaos texture

Figure 1: Map of portion of E11 Regional Map image. Black indicates contacts between chaos units (white, yellow, red, blue, and green) and background plains (gray).



(Figure 1). The features range from 3.2 km to 156 km in diameter, with a median of 8.8 km [8]. 75% of these features qualify as individual lenticulae containing micro-chaos based on overall morphology. Our mapping reveals that there are lenticulae features that appear to be inter-connected. Figure 2 shows several examples of possibly merged lenticulae based on internal structure of the feature and the irregular shape of the boundaries. We found 8 features that appear to be double lenticulae, 3 features which may be triple lenticulae, and 4 larger regions which appear to be either more than 3 merged lenticulae or chaos features. We measured the minimum areal density of lenticulae in a 100 km^2 area of this region and then used that value to determine the minimum number of lenticulae that might be present in the largest chaos region; it has a surface area that can accommodate at least 39 median sized lenticulae. The irregular shape of the chaos region also suggest lenticulae coalesce as we see many lenticulae-like areas at the boundaries of the chaos region. The mapped region has structural features (violet) that are concentric and radial to the larger chaos areas. There are also other fractures at the edges of the chaos borders that have dislodged blocks, which appear to have broken off into the chaos region. We observed several low-albedo smooth areas (spots; cyan) occurring within chaos. Our mapping indicates that the chaos and lenticulae are stratigraphically very young features, as they are only occasionally crosscut by troughs and double ridges.

Additional images were recently obtained during the Galileo Europa Mission (E17) which focus on a sharp boundary between mottled terrain and bright terrain. These images were taken at 55 meters/pixel and are centered at (31˚S, 189˚W). They reveal a chaos area in the northeast, surrounded by lenticulae, lineae, and fractures. We mapped the northern area using the same methods we applied to the E11 region. Once again we found spots of darker, smooth material within the chaos region. There is also an abundance of cracks that appear to connect chaos and lenticulae. Blocks at the chaos boundaries are inferred to have been dislodged into the chaos by fracturing. There are some isolated sets of fractures outside the chaos region that have apparently dislodged blocks in between. We found that chaos and lenticulae in this area are also stratigraphically young.

Summary: 1) Chaos is defined as irregularly-shaped areas containing matrix and commonly containing linear-textured polygonal blocks. Matrix can be further subdivided into several units: angular polygonal material, micro-polygon material, peak material, and hummocky matrix. The areas of chaos and lenticulae that we have studied have also been found to be stratigraphically very young. 2) The micro-chaos textural material within lenticulae can be mapped using our chaos units, thus demonstrating that lenticulae and chaos share similar textural morphology and scale. Chaos and lenticulae may be characterized by similar processes operating during their origin. 3) Chaos may grow in size by localized fracturing and incorporation of surrounding lenticulae. Genetic relationships between chaos and lenticulae are suggested by: pathways of chaos materials connecting chaos and lenticulae, fractures connecting lenticulae and chaos, the presence of merged lenticulae, and the slumping and inward translation at chaos boundaries. Dislocated blocks occurring between sets of fractures may indicate an early stage of chaos formation.

This work has shown that it is possible for some chaos to be created through a coalescence of lenticulae. Therefore, chaos may be the combination of several smaller rising diapirs which disrupt the areas between them. The irregular shaped chaos areas we have mapped do not support an origin of chaos by discrete large-scale upwellings or melt-throughs, where one might expect to see coherent ovoidal areas. Instead, a coalescing of lenticulae is able to explain both the irregular shapes of some chaos regions and of merged lenticulae.

Ongoing work includes the analysis of other chaos regions and an examination of the role of lenticulae in their formation. We are working to constrain models of chaos and lenticulae formation by studying the spacing of these features in mottled terrain, the size of blocks within chaos areas, and the relation of fractures to chaos.

References: [1] Lucchita, B.K. and L.A. Soderblom, The geology of Europa, in *Satellites of Jupiter*, (D. Morrison, ed.), University of Arizona Press, 521-555, 1982. [2] Pappalardo, R.T. et al., Geological evidence for solid-state convection in Europa's ice shell, *Nature*, **391**, 365-368, 1998. [3] Carr, M.H. et al., Evidence for a subsurface ocean on Europa, *Nature*, **391**, 1998. [4] Head, J.W. et al., Evidence for recent solid-state convection on Europa, *Bull. of the Am. Astronom. Soc.*, **29**, 983, 1997. [5] Head, J.W. et al., Lenticulae on Europa: The nature and distribution of pits, spots, and domes in the Conamara region, in preparation. [6] Spaun, N.A. et al, Conamara Chaos Region, Europa: Reconstruction of mobile polygonal ice blocks, *Geophys. Res. Lett.*, **25** (23), 4277-4280, 1998. [7] Spaun, N.A., et al., Chaos and Micro-Chaos: Mapping, unit Descriptions, and origins, *EOS Trans. AGU*, 79(45), P22B, 1998. [8] Spaun, N.A. et al., Longitudinal distribution of chaos and lenticulae on Europa, LPSC 30, 1998.

Figure 2: Examples of probable merged lenticulae. Pictures taken from our map, superposed over E11 Regional Map image. White arrows indicate features that are the scale and morphology of individual lenticulae. Colors correspond to chaos units defined in text.