GEOLOGICAL MAPPING AND STRATIGRAPHY OF THRACE AND THERA MACULA, EUROPA.
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Introduction: Chaotic terrains on the icy moon Europa are among the youngest surface features within the satellite's visible geological history [1]. These regions appear as highly disrupted surfaces formed by irregular groups of isolated plates surrounded by a lumpy matrix material [2]. They are often covered in a reddish-brown material that is interpreted to consist of hydrated sulfates [3] or sulfuric acid hydrate [4]. Current models of chaos formation include a melt-through of the surface provoked by an internal heat source (i.e. a hydrothermal plume) [5], or the mobilization of brines trapped near the surface, in response to partial melting of the outer shell induced by icy diapirs rising through the crust [6]. In this paper we investigated two chaotic terrains named Thrace Macula and Thera Macula, both located on the southern hemisphere of Europa. First imaged by the Voyager 2 spacecraft, the two maculae were originally interpreted to result from cryovolcanic activity [7]. Later works supported by higher-resolution images acquired by the Galileo spacecraft showed that upwarping of surface followed by extrusion of low-viscosity liquids [8] [9], collapse of large-scale domes [10], or interactions between ice and shallow subsurface water lenses [11] may better explain how the two maculae have formed. Here we provide a geomorphological and stratigraphic analysis of Thrace and Thera Macula, derived from an extensive geological mapping based on the highest-resolution images of the area acquired throughout the Galileo space mission.

Results: The mapped area includes plains dominated by ridge complexes, bands, linear features (double ridges, troughs), craters (for less than 1%), and chaotic terrains. Bands and double ridges display a high variety of arrangements and intersections, with local displacements suggesting occurrence of crustal movements along tectonic faults. Thera Macula is characterized by a distinctive dichotomy between its northern, partly fractured sector devoid of dark material, and the southern complex of low-albedo chaotic terrains. The margins of the macula, particularly to the north, appear heavily fractured and forming a complex of scarps faced towards the macula. The dark, chaotic terrain consists for 85% of matrix material, and for 15% of large plates that show signs of displacement. The matrix is almost entirely confined within the system of inward-facing scarps, except for isolated patches of matrix that lie above the surrounding terrains. Apparently, the matrix has replaced a pre-existing terrain which underwent a strong degradation process.

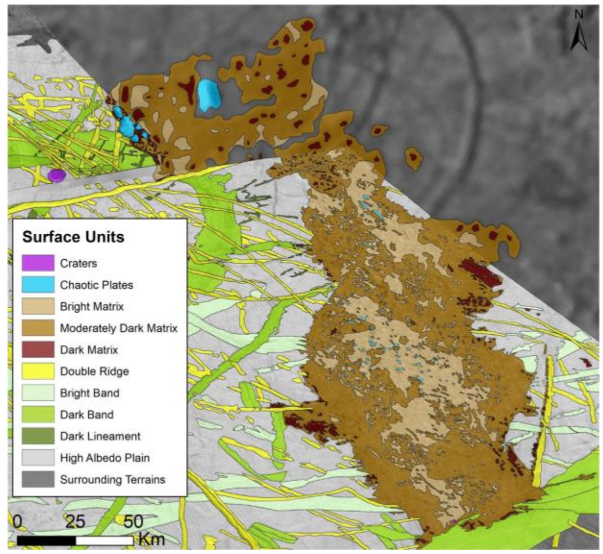

Figure 1 Geological Map of Thrace Macula.

Thrace Macula exhibits a large proportion of matrix material, which makes up to 98% of the macula's surface, while the remaining 2% is composed of blocks (Fig. 1). The latter are represented either by large, well-defined plates, only identified in the northern sector, or by small sub-kilometer, often tilted blocks found in the center of the macula. In contrast to Thera, the boundaries are not marked by steep scarps, and the matrix looks domed up above the surrounding plain. The macula's northern and central sectors are separated by a bright, roughly linear stripe that could be an intersecting double ridge postdating the formation of the macula. The high-resolution images of the southern lobe show the presence of a higher-albedo matrix, where any pre-existing structure is no longer recognizable, and a lower-albedo matrix, where the pre-existing features are still preserved and appear mostly unaltered. High-resolution images also allow detection of many sub-kilometer sized craters, often arranged in local clusters, and those in the chaotic terrain are usually covered in the low-albedo smooth matrix originating from the macula, suggesting an earlier formation of the craters.

Discussion: Geological mapping has revealed that around the "non-chaotic" plains are structures intersected by linear features (troughs, double ridges, bands), that appear displaced along two opposite directions. Such displacements suggest that blocks of terrain may have moved in response to tectonic stresses occurring along strike-slip faults or extensional margins. A graphic reconstruction of the original placement of surface units has allowed to confirm that lateral and extensional motion of the icy crust has occurred at some point during Europa's geological history, generating linear displacements up to 7.50 km in length.

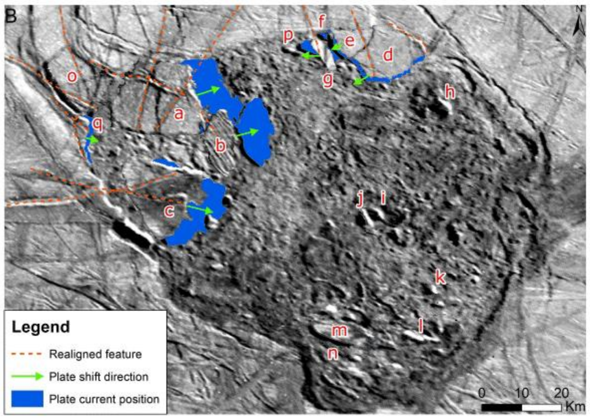

Figure 2 Reconstruction of plates in Thera Macula to their expected positions prior to shifting.

Furthermore, the morphology and the orientation of the plates surrounded by the chaotic matrix in Thera Macula indicates they must have undergone shifting, rotation and tilting upon their formation. A reconstruction of the original placement of 17 plates has confirmed that 47% of them have undergone horizontal translation, moving between 0.7 and 9.2 km (Fig. 2). Also, 30% of the plates have rotated by an average of 10.6°, either clockwise or counterclockwise, whereas motion of the plates has prevalently occurred from the inward-facing scarps towards the innermost areas. A comparison with the plate reconstruction performed by Spaun et al. in Conamara Chaos [12] has revealed consistency in the average rotation amount and shifting directions. In contrast, the average shifting distance of plates is higher in Thera, and most of them have rotated clockwise rather than counterclockwise.

Finally, we inferred the relative age of the two maculae and the variety of geological features that comprise the surrounding plains by performing a detailed analysis of cross cutting relationships. The resulting stratigraphic column can be summarized in a four-stage sequence of events: 1) Formation of plains, including ridge complexes and smooth plains; 2) Formation of bright bands and isolated double ridges; 3) Formation of dark bands and additional linear features; 4) Formation of impact craters and chaos regions, with Thrace Macula possibly having formed earlier than Thera (Fig. 3).

In the future, we plan to produce digital elevation models using photoclinometric techniques to add topographic constraints to the investigated area.

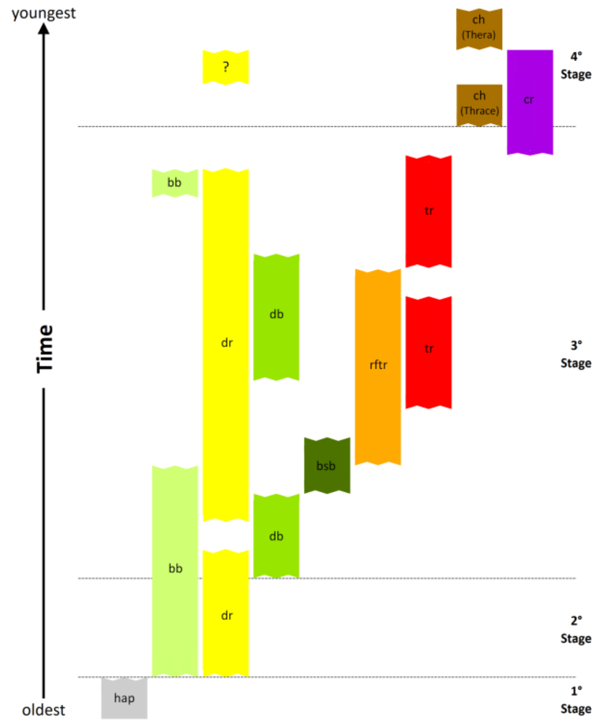

Figure 3 Stratigraphic chart of surface features. Unit abbreviations: high albedo plains (hap), bright band (bb), bilaterally symmetric band (bsb), dark band (db), double ridge (dr), raised-flank trough (rftr), trough (tr), chaos (ch), crater (cr).

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References: [1] Prockter L. M. et al. (1999), *JGR*, *104*, 16531-16540. [2] Collins G. and Nimmo F. (2009), in *Europa*, *U. Arizona Press*, 259-281. [3] Dalton J. et al. (2005), *Icarus*, *177*, 472-490. [4] Carlson R. W. et al. (2002), *Icarus*, *157*, 456-463. [5] Greenberg R. et al. (1999), *Icarus*, *141*, 263–286. [6] Head J. W. and Pappalardo R. T. (1999), *JGR*, *104*, 1999. [7] Wilson L. et al. (1997), *JGR*, *102*, 9263-9272. [8] Fagents S. A. (2003), *JGR*, *108*, 2003. [9] Miyamoto H. et al. (2005), *Icarus*, *177*, 413-424. [10] Mével L. and Mercier E. (2007), *PSS*, *55*, 915-927. [11] Schmidt B. et al. (2011), *Nature*, *479*, 502–505. [12] Spaun N. A. et al. (1998), Geoph. Res. Lett., 25, 4277-4280.