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Astrobiological implications of chaos terrains on Europa to help targeting future missions

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ABSTRACT

Reviewing the results from different authors on the ice crust and supposing the presence of an internal ocean inside Europa, chaos terrains and various lenticulae features might be in connection with submarine geothermal centers while pull-apart terrains and other linear features are probably in connection with tidal processes. Ranking the surface features according to the possibility how much are they connected to deep submarine processes, the above mentioned first group is more important than tidal related linear features.

Surveying the size and height of blocks at the example terrain of Conamara Chaos we found that the thickness of the ice crust during its formation could be around 2 km at the rafts and 0.5 km at the matrix in agreement with some other authors' estimated values. Calculating the hydrostatic pressure at the bottom of the approximately 25 km thick ice crust 10 000–20 000 kPa was estimated, and at the bottom of a 100 km deep ocean at the order of 150 000 kPa was found. At such pressure and assumed temperature, volcanic gases became dissolved in the water—although clathrates might also form, and could be released later as gas bubbles. This process was enhanced during the formation of chaos terrains if the ice crust thickness is only 2 km at the active phase and the pressure is around 2400–3100 kPa at its base, or inside a subsurface brine lens still roughly 100 times smaller than at the bottom of the ocean. Calthrate decomposition and bubble formation might be the most intensive at chaos regions and bubbles may be trapped between ice grains (McCord et al., 1999) or inside clathrate structure (Prieto-Ballesteros et al., 2004). Using terrestrial analog observations we conclude that trapped bubbles might be detectable remotely by the difference in the infrared and visual albedo, and by other scattering properties. The rationality of such observations is the highest at those units of the chaos regions' low level matrix, where the smallest linear structures are present suggesting the strongest disruption, but they are not covered by debris aprons. The possibility of the detection of gas bubbles or other material floating upward in the warm rising plume is of high interest at chaos terrains, and development of detecting methods for the next Europa mission is useful.

1. Introduction

The aim of this work is to outline our present day knowledge as a review, comparing the astrobiological importance of different surface feature types on Europa. Below the ice crust a liquid ocean may be present based on several issues, like on the tectonic features suggesting the sliding of the crust as a single unit (Schenk and McKinnon, 1989), on the analysis of the shape and depth of craters, and on the changeable magnetic fields measured by Galileo orbiter (Kivelson et al., 2000; Zimmer et al., 2000). This liquid water layer is important for astrobiology (Kargel et al., 2000), especially because it is in direct contact with the deep silicate crust of the satellite (Carr et al., 1998). Based on theoretical computations and some observations, the tidal effect (Sotin et al., 2009) might release heat inside Europa (Ross and Schubert, 1987) and it leads to volcanic activity. Geothermally heated locations of silicate rocks together with liquid water are of high importance (Goodman and Lenferink, 2009) as the conditions there might be favorable for prebiotic synthesis and various chemical reactions (Sleep and Hessler, 2006; Macleod et al., 1994; Wacey et al., 2010) that are important for the origin of life. Although we do not have direct access to observe submarine locations there, the analysis of various surface features on the ice crust, like lenticulae or chaos regions (Doggett et al., 2009; Nimmo and Manga, 2004) may give indirect information to approach the style and effect of submarine hydrothermal activity. In this paper, we are discussing the possibility

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of where and what kind of surface manifestations should be searched for in this aspect.

The secondary aim of this article is to outline the probable important targets and observation types of a possible mission like JUICE (Jupiter and Icy moons Explorer) based on the review works (Dougherty et al., 2011) with orbiters, landers (Gowen et al., 2011; Zelenyi et al., 2011) and even melting probes (Biele et al., 2011; Weiss et al., 2011). The JUICE ESA mission international project is aimed at the detailed analysis of Jupiter and its satellites focusing on Ganymede and Callisto, although flybys dedicated to explore Europa are also included in the mission plan. In this work we outline some ideas and model approaches that may be useful targeting the observations of these missions and also may give useful points during the planning phase.

The third aim is to realize some simple numerical computation on the possible ice thickness at the chaos terrain where most detailed data are available. Here we analyze the astrobiological importance of each terrain type in order to see how they might hold important information about the submarine volcanic activity and astrobiological significance of the inferred conditions.

2. Methods

In this work for the review section we used already published results from other authors. Analogs from the Earth are also presented here to make a complete picture of the estimation of astrobiological importance of different terrain types. Beyond the review issues, two research topics are summarized here. We calculated submarine pressure values inside the ice and inside the ocean by simple physical formula, and estimated crust thickness during chaos terrain formation. For the crust thickness estimation we used GIS and graphical software (Surfer, Photoshop, details below) and statistical methods.

Because higher activity in the crust by cracking and rotation occurs at chaos terrains we analyzed these regions as indicators of the structure and thickness of the ice crust. Based on the Galileo spacecraft's images published at Planetary Data System, just like earlier works (Greeley et al., 1998; Spaun et al., 1998) we estimated the thickness of the crust with somewhat different method with the relative height of the "icebergs" (based on their shadows), and using Airy isostasy models. With this we can approach the relative thickness and thickness variations of the Europa's crust at the analyzed terrain, which could be interesting information among the other thickness estimation methods. Only the images obtained by the Galileo spacecraft (Moore et al., 1998; Prockter et al., 1998) with up to 54 m resolution were used. Two parameters were surveyed on the images: the diameter of the individual rafts (Greenberg et al., 1999) that are elevated above the low level hummocky matrix, and the shadow length of these heights. On the images we marked the width of these shadows according to the lighting direction, measuring the physical distances of the pairs of pixels: the beginning and end of the shadow is parallel to the lighting direction. Analyzing the horizontal length of shadows, with simple trigonometric transformation we gave the height of the surface structure relative to the surrounding terrain. The estimated errors from manual pointing accuracy in the measurements are below 20%, and the results were used only for statistical analysis. We measured the size and relative height above the surrounding terrain of the blocks inside a 48 × 38 km part of the Conamara Chaos. In Fig. 1, the theoretical approach of our model is shown: during the breaking phases blocks the heights of which are greater than their width (their shape is "tall") rotated into more stable drifting position.

We used three basic statements to calculate the ice crust's parameters: (A) the ice crust and blocks are in isostatic equilibrium.

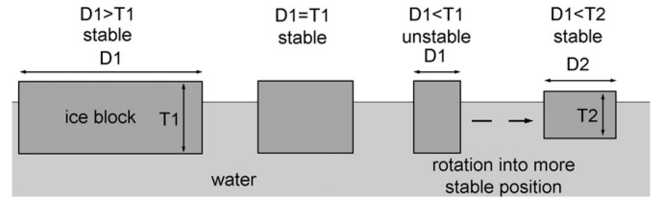

Fig. 1. Schematic representation of the block rotation model. When the diameter (D) is substantially larger than the height (T) of a block, it is in stable position. But when the case is opposite ($T < D$) this produces unstable position that makes the block to rotate and its height to get substantially smaller.

(B) The pure ice is homogeneous and has a density of 917 kg/m^3—although the ice could be contaminated at the chaos terrains, but the exact composition is poorly known, but it contains salt hydrates or sulfuric acid hydrates, as well as the implementation of behavior of the non-ice material during freezing. Besides the isostatic situation the internal plasticity and the deformation assumed do not influence the drift of the rafts.

3. Overview of our current knowledge

In this section we summarize our current knowledge regarding the astrobiological relevance of various surface features on Europa. Although there are models on the possibility of niches and living organisms inside the ice crust (Greenberg et al., 2000; Hand et al., 2007; Marion et al., 2003; Seckbach and Chela-Flores, 2007; Chela-Flores, 2006), here we focus on the proposed submarine volcanic and geothermal activity. If a global ocean exists on Europa below the ice crust, based on the models of the interior structure and the thickness of the ice layer, high pressure ice is not expected in the deep subsurface but silicate rocks might be present in 100–150 km depth (Kuskov and Kronrod, 2005). The tidal heat probably produces volcanic activity in the silicate crust (Ojakangas and Stevenson, 1986). Using these assumptions one can expect more bio-relevant chemical reactions where geothermal heat sources together with large mineral surfaces in physical contact with liquid water are present, as prebiotic processes might happen there, and energy source might also be available for hypothetical organisms. These are among the best locations on the satellite to search for biosignatures.

European submarine volcanism is interesting for both geology and astrobiology related investigations. Based on the estimated global heat flux in the crust, which is around 0.02 Wm^{-2} (Squyres et al., 1983; Hussmann et al., 2002) but could be substantially higher at geothermal centers (Spencer et al., 1999), volcanoes on the surface of silicate crust are expected. Submarine volcanism may be present on Europa not only because of the thermal computations but also by the presence of various surface structures suggesting melt-through of the ice from below—although there are models that do not require submarine volcanoes. In the case of submarine volcanism the eruption temperature, gas content and chemistry are also interesting factor that influence the solution, precipitation, and particle formation in the material released by volcanism. Using analogs on the Earth, we can assume that at these submarine volcanoes fast cooling of lava (Cas, 2006), volcanic glass (Stolper et al., 2004; Bowles et al., 2005) and lava crust formation (Kueppers et al., 2009) might be present. The lava could be shattered into fragmental debris (Clague et al., 2000; Davis and Clague, 2006) there with diverse morphology often depending on the eruption rate (Griffiths and Fink, 1992). Unlike terrestrial lava flowing on Earth, the interior of European submarine pahoehoe flows contains complex voids from boiling seawater (Lockwood and Hazlett, 2010) and significant vapor may accumulate below the thick crust of chilled