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Timing of chaotic terrain formation in Argadnel Regio, Europa, and implications for geological history

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ABSTRACT

Chaos terrains are among the most prominent landforms of Europa, and are generally among the youngest features recorded on the surface. Chaos units were formed by to endogenic activity, maybe related to solid-state convection and thermal diapirism in the ice shell, perhaps aided by melting of salt-rich ice bodies below the surface. In this work, we analyze the different units of chaotic terrain in a portion of Argadnel Regio, a region located on the anti-Jovian hemisphere of Europa, and their possible timing in the general stratigraphic framework of this satellite. Two different chaos units can be differentiated, based on surface texture, morphology, and cross-cutting relationships with other units, and from interpretations based on pre-existing surface restoration through elimination of a low albedo band. The existence of two stratigraphically different chaos units implies that conditions for chaos formation occurred during more than a single discreet time on Europa, at least in Argadnel Regio, and perhaps in other places. The existence of older chaos units on Europa might be related to convective episodes possibly favored by local conditions in the icy shell, such as variations in grain size, abundance of non-water ice-components, or regional thickness of the brittle lithosphere or the entire ice shell.

1. Introduction

Chaos terrains are among the most prominent landforms of Europa, and are characterized by the disruption of the pre-existing surface, which is broken into plates of various sizes in a dark and rough matrix (Carr et al., 1998). Chaos terrains are formed due to endogenic activity, most probably related to solid-state convection and thermal diapirism in the ice shell (e.g. Pappalardo et al., 1998,1999; Greeley et al., 1998; Collins et al. 2000), perhaps aided by melting of salt-rich ice bodies below the surface (Head and Pappalardo, 1999; Pappalardo and Barr, 2004; Schmidt et al., 2011). In chaos areas, a substantial part of the original surface has been destroyed, although pre-existing structures can be preserved on surviving chaos blocks, which helps us to understanding the previous disposition and movement of these plates (Spaun et al., 1998; Greenberg et al., 1999). Chaos terrains are located towards the top of the stratigraphic sequence of Europa (see Doggett et al. (2009), and references therein), implying that those terrains are in general among the younger structures recorded in the surface. Following the general stratigraphy inferred by Greeley et al. (2000), the oldest recognizable unit on Europa is the background ridges plains, which are characterized by structures such as older brightened bands and large ridges, while chaos terrains generally cross-cut most other units.

However, although that general stratigraphic sequence is approximately representative across Europa's surface, there are documented some examples of chaos terrains affected by younger landforms (Greenberg et al., 1999; Figueredo and Greeley, 2000; Hoppa et al., 2001; Prockter and Schenk, 2005; Riley et al., 2006; Collins and Nimmo, 2009). For example, a chaotic terrain unit at Castalia Macula, classified as "knobby chaos material" (indicating a substantial level of surface disruption), only affects the background ridged plains, whereas the unit is in turn affected by younger smooth plains and chaos (Prockter and Schenk, 2005). Similarly, Riley et al. (2006) have described, in a region close to the south pole, two different chaos terrain units formed in different times and with several other units stratigraphically placed between the chaos units. Moreover, Doggett et al. (2009) proposed a global mapping of Europa geology. That defined several chaos units, including a unit (Chaos 1 unit after their terminology) corresponding to older chaos terrains which disrupt the background ridged plains but usually are cross-cut by individual ridges, bands, lenticulae or younger chaos units.

In this work we analyze the crossing relations between chaos terrains and other geologic structures (mostly bands), as well as

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between different chaos patches, in Argadnel Regio, in the anti-jovian region of Europa. Our aim is to place the events of chaos formation into the overall stratigraphic framework of this region, and then to discuss the implications of our results for the local geological history of this jovian moon.

2. Study region

Argadnel Regio, also dubbed the "wedges region", is 1900 km across and is located in the anti-jovian hemisphere of Europa. The region is characterized by the presence of several generations of cross-crossing wedge-shaped bands of relatively low albedo material (Schenk and McKinnon, 1989; Sullivan et al., 1998; Prockter et al., 2002). This region was first studied on the basis of Voyager imagery (Schenk and McKinnon, 1989), and later has been imaged with improved resolution during the 3rd, 12th, and 14th Galileo orbits. In this work we have used the image mosaic 14ESWEDGES01, obtained during the 14th Galileo orbit with the solid-state imaging (SSI) system camera, which has a mean resolution of ~233 m per pixel (Fig. 1). Specifically, we analyze the central part of this mosaic, which is centered on 22°S and 179°W and covers an area of 240 by 215 km.

This area of Argadnel Regio has been previously studied by several workers. Prockter et al. (1999) performed the first preliminary geological mapping and stratigraphic analysis of the mosaic studied here. Later on, Shirley et al. (2010) performed more detailed mapping covering in a part the same mosaic, south of our study area, and they combined Galileo SSI images and spectroscopic data from Near-Infrared Mapping Spectrometer (NIMS). Moreover, Schulson. (2002) and Kattenhorn and Marshall. (2006) performed detailed structural analysis of the bands in this region. We build on this previous work, considering the diversity of landforms and terrains that permit us to recognize cross-cutting relationships, and hence establish relative age and positions on the regional stratigraphic column.

3. Chaos units

Chaos units can be distinguished by texture, morphology, matrix proportion, and relative stratigraphic position with respect to other landforms (see for example, Prockter et al., 1999; Greenberg et al., 1999; Greeley et al., 2000; Collins and Nimmo, 2009). Chaos units can be identified in two separate zones of the study area (Fig. 2), which we denote for clarity as zones A (western zone) and B (eastern zone). We define two chaos units in zone A, referred to as Chaos Unit 1 (Ch1) and Chaos Unit 2 (Ch2), which appear in close association with two prominent bands, and which below we argue are placed in different temporal positions of the local stratigraphic column. Similarly, in zone B, at least two chaos units can be characterized, which we consider as equivalent to the chaos units in zone A. However, because there is not physical connection between the chaos units in zones A and B, we refer to the units in zone B as "Ch1-like material" and "Ch2-like material". Next, we will describe both chaos units, as well as the cross-crossing relationships with the adjacent geologic materials.

3.1. Chaos Unit 1 (Ch1)

This class of chaos terrain (Fig. 3, dark green) presents an irregular morphology (varies in its internal appearance), with a relatively smooth matrix, and with scarce plates or blocks. Because of its lesser proportion of preserved bright plates, this unit is characterized by a low and very homogeneous albedo in zone A. The chaos boundaries are well defined because the chaos materials are darker than the surrounding material and the boundaries are relatively sharp. However, in area B, Ch1-like material (Fig. 3, hatched dark green) show a higher albedo, because chaos units in this part of the surface have brightened through sputtering or frost deposition following their formation. In any case, the boundaries of Ch1-like material in zone B have a relatively low albedo overall, facilitating their mapping. This chaos unit is cross-cut by younger structures: a dark band, a lineated band, and a second class of chaos terrain (Chaos Unit 2, described below). This first chaos unit is inferred be equivalent to those defined in previous work as "knobby chaos" (Greeley et al., 2000) or "modified chaos" (Greenberg et al., 1999).

3.2. Chaos Unit 2 (Ch2)

Chaos Unit 2 (Fig. 3, light green) is characterized by a more heterogeneous matrix (and hence more variable albedo), in which plates (showing evidence of the pre-existing surface) and smaller blocks are commonly preserved. The Ch2 general morphology is the same throughout the unit, presenting changes in albedo and texture, highlighting the inferred general disaggregation of the surface into small plates or blocks. Thus, while in Ch2 the disruption is uniform, and has a similar texture throughout the unit, Ch1 varies in its internal appearance. The boundaries of this unit

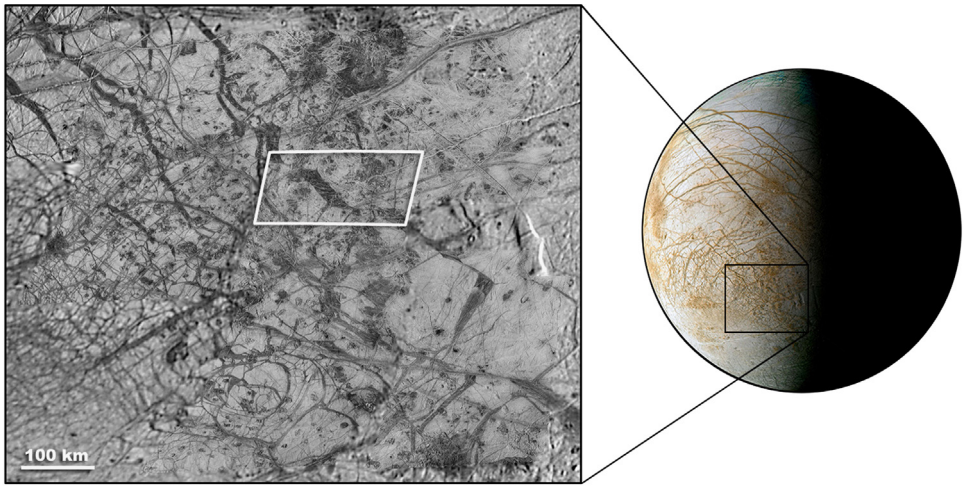

Fig. 1. Mosaic of Argadnel Regio (Galileo observation 14ESWEDGES01), the "wedges" area of the anti-jovian region of Europa, obtained during the 14th Galileo orbit. The white box indicates the study area (20°S to 24°S, and 184°W to 175°W).

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