12th International Workshop on Modeling of Mantle Convection
and Lithospheric Dynamics

August 20th to 25th 2011, Döllnsee Germany

The Diversity of Ridges on Europa: Implications for Formation

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Many generations of linear and curvilinear ridges cover the surface of Europa, an icy satellite of Jupiter [1,2]. The origin of these features may help constrain the thermal structure of the Europan crust and possibly the presence of a subsurface ocean over geological timescales [3,4]. We explore how the diversity of observed morphologies constrains possible formation mechanism and the mechanics of the Europan ice shell.

Based on images from Voyager and Galileo, previous workers have differentiated between several ridge morphologies, including double ridges, complex ridges and cycloidal ridges [5]. Double ridges are near-linear features with a single trough flanked by two parallel ridges. Complex ridges are features with several adjacent ridges that can be either parallel or anastomosing. Unlike the essentially linear ridges, cycloidal ridges are curvilinear features and often form in chains of arcing segments joined by a sharp cusp [6,7].

Proposed mechanisms for the formation of ridges on Europa include shear heating [8,9], cryovolcanism [10], incremental ice wedging [11] and tensional cracking under the influence of Europa's nonsynchronous rotation [12,13] and generally cyclic stress field [4]. While each of these mechanisms could potentially play a role in the formation of one or more of the ridges types seen on Europa, none is able to explain all three. Our study of the entire Galileo Solid State Imaging dataset reveals that the differences in morphology between these ridge types are blurred. There is a continuum of morphologies between each ridge type. Along-strike transitions from one type of ridges to another are observed. A complex ridge may include branches that could be classified as a double ridge for a portion of their lengths. Some double ridges are observed to suddenly obtain the arcing trajectory of a cycloid. Transitional morphologies such as cycloids with smooth cusps are also visible.

The absence of a fundamental difference between the morphology of each ridge type implies that a similar mechanism at work on the three classes of these ridges. We propose that liquid water fills tension cracks that open in the Europan crust in response to tidal stress and possible overpressure of a subsurface ocean [14,15,16]. Volume expansion upon crystallization of the cracks would buckle the adjacent crust [11] and form a single or double ridge morphology depending on rate of crystallization. Complex ridges would form by repeated intrusions. Strike-slip offset are possible if the intrusion remains liquid for long enough but are not a primary mechanism for ridge morphology. The passive intrusion mechanism can provide a unifying concept to explain the diversity of ridge morphology and transitional morphologies on Europa.

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