THE ROLE OF PLASTIC DEFORMTION AND CRYSTALLIZING WATER INTRUSIONS IN EUROPAN RIDGES. S. J. Johnston and C. D. Author[1], L. G. Montési[1], [1]Department of Geology, University of Maryland, College Park (johnston@umd.edu; montesi@umd.edu).

Introduction: Based on cratering estimates, Europa's surface is thought to be only 30-70 Myr old [1]. Even though the surface is geologically young, it is marked by a variety of features, including ridges. Based on images from *Voyager* and *Galileo*, previous workers[2,3] have differentiated between several ridge morphologies, including single ridges, double ridges, complex ridges. A successful model for the of Europan ridges should be able to account for the observed diversity of morphology and for the presence of transitions from one morphology to another along strike.

The previous finite element models of the elastic deformation related to a crystallizing water intrusion show that the cross section of the intusion has first order control on the morphology of the ridge created at the surface[4]. Using a similar model setup but with plastic rheology, a similar control on the morphology is observed. Adding plastic deformation to the model allows for a more realistic determination of the deformation associated with the freezing of a water intrusion. By including material properties for the intrusion as well as the shell, the impact of the intrusion rheology on the deformation is able to be determined. The height of the surface deformation with a plastic rheology and rigid intrusion is less than that observed with the elastic but the rigidity of the intrusion also constrains the amount of deformation allowed in the model.

Ridge Morphologies: Existing models of ridge formation have focused on the development of specific features, most notably double ridges and cycloids, but the presence of transitional morphologies and along-strike transitions from one category to another suggests that a successful model should be able to explain all the observed morphologies.

The most ubiquitous ridges have a central trough flanked by two raised edifices [5], called a double ridge. Double ridges are commonly long linear features that can extend 100s of km and consist of two peaks separated by a central trough. The trough can be narrow or wide. Double ridges have an average height of a few hundred meters and width less than 5 km. Some ridges appear to have flanking cracks. Single ridges are also observed on Europa, these structures are ridges that appear to lack the central trough. Complex ridges display a range of morphologies including anastomosing or near-parallel ridges, ridges flanked by narrow troughs and ridges with a modified summital trough, featuring a flat floor or an irregular ridge [4].

Ridge Formation: Proposed mechanisms for the formation of ridges on Europa include shear heating[6,7] cryovolcanism[8] and incremental ice wedging[9]. While each of these mechanisms could potentially play a role in the formation of ridges on Europa, they have difficulty explaining the entire diversity of ridge types, the presence of transitional morphologies, and the similarity between ridges and cycloids.

The lack of segmentation in ridges motivates us to explore formation mechanisms related to fluid intrusion rather than faulting. We assume that liquid water fills tension cracks that open in the Europan crust in response to tidal stress or perhaps overpressure of a subsurface ocean[10,11,12,13,14]. The crack would be long and essentially continuous, similar to dikes on Earth. The crack may adopt a cycloidal trajectory under a time-variable diurnal stress cycle. The freezing of the water would cause a volume expansion, compressing and buckling the adjacent crust[8].

The model utilizes the commercially available finite element software package Abaqus. It models the ice ice deformation around a crystallizing intrusion, improving on the previous elastic model by including plastic deformation to evaluate the impact of plasticity on the observed deformation and to evaluate regions of possible brittle failure. The numerical model is set up in 2-D, as a cross-section of the ice shell taken perpendicular to the water intrusion. Gravity is imposed on the entire model with an elastic foundation at the base of the ice shell in order to simulate the restoring force of an underlying ocean. The surface is stress free and the lateral edges of the model are stress free vertical walls that prevent extension of the ice layer as a whole. An initial geostatic stress is imposed on the entire model in order to support internal stresses and prevent premature brittle failure. An elastic-plastic rheology with a von Mises failure criterion is used for both the shell and the water intrusion. The volume change associated with crystallization of the water-ice intrusion is represented by a prescribed overpressure at the intrusion boundary.

We find that the geometry of the intruding dike has a major impact on the ridge morphology. Specifically, the aspect ratio of the water intrusion is the principal determining factor in whether a double or single ridge is observed on the the surface.

In the previous elastic model a double ridge height up to 425m was achieved and a the single ridge reached as high as 720m. Adding plasticity to the model has greatly reduced the ridge height obtained to

~10m for the double ridge and ~40m for the single ridge. This reduced ridge height is not only a result of the plastic rheology but also appears to be influenced by the ridigity of the intrusion itself, which reduced the amount of deformation at the intrusion-shell boundary.

Based on the von Mises stresses observed (Figure 1) it is apparent that plastic deformation is of great importance when considering the deformation caused by a crystallizing water intrusion. The von mises stresses show in Figure 1 range from zero to 1MPa. At or above the yield stress of 1MPa red is shown in the figure.

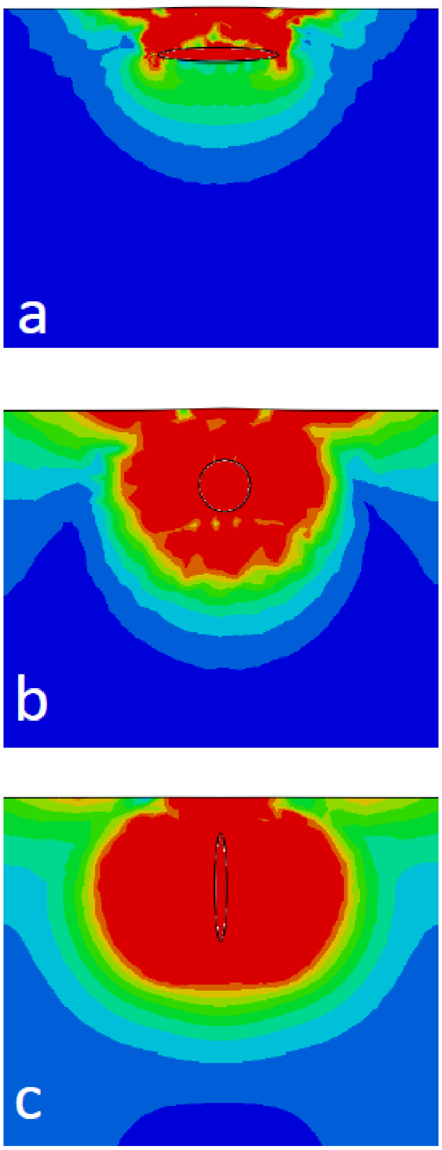

Figure 1. The von mises stress for a) a sill like intrusion b) circular intrusion and c) dike like intrusion. The red shows von mises stresses greater than the yield stress of 1MPa.

Implications: While the addition of plasticity to the previously elastic model of a crystallizing water intrusion has significantly changed the surface deformation obtained the cross sectional geometry of the intrusion still appears to exert first order control of the type of ridge observed at the surface.

A higher double ridge height may still be possible if the ridigity of the intrusion can be reduced to values more consistent with water rather than water-ice. In any case, considering the plastic behavior of the deforming ice had a significant influence on the deformation observed and the over all morphology of the ridge.

References:

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Acknowledgement: This work is supported by the NASA Grant NNX10AG41G.