INVESTIGATIONS OF CRATER INDUCED FRACTURE MECHANICS AT EUROPA. A. Chen[1], K. L. Craft[2], M. Rudolph[3], [4] A. R. Rhoden, [1]Johns Hopkins University, Baltimore, MD, (achen126@jhu.edu), [2]Johns Hopkins Univ. Applied Physics Laboratory, [3]Department of Earth and Planetary Sciences UC Davis [4]Southwest Research Institute, Boulder

Introduction: Over 390 million miles away orbiting around Jupiter resides the icy moon of Europa, and scientists believe that underneath the icy crust hides an ocean of salty water many kilometers deep. With Europa being similar in size to our moon, having around a 100 kilometer deep salty ocean and an induced magnetic field, it sparked immense curiosity over the premise that the ocean beneath may hide traces of extraterrestrial life. Europa has a highly fractured surface, but with a dearth number of craters that are impacted by the tidal forces present. Since Europa's orbit is elliptical and its distance and gravitational pull from Jupiter varies throughout orbit, it creates tides that stretch the moon's surface.

Even though there is potential for habitability or life within the subsurface ocean, there has been a limited number of missions that have reached Europa. Due to the difficulty with reaching these bodies, many scientists have turned to computer modeling to investigate the effects of geological events on Europa's ice shell. The goal in this study is to investigate the response of a cooling and thickening fracture once disturbed by an impact crater. Once an impact occurs, the fluid melt that is produced may enter the fracture and will pressurize the crack as the melt begins to freeze. The stresses are examined to see if the fracture could propagate to the subsurface ocean or could connect to deep cracks and other nearby fracturing.

Model Set-Up: Ansys Mechanical is an engineering software used for structural analysis which was used to design a 2-dimensional geometry of Europa's ice shell (Figure 1). In order to accurately model the environmental conditions on Europa the material properties were specified to match those of water ice. (Young's Modulus = 9.1 GPa; Poisson's Ratio = 0.3; Density = 920 kg/m^3) [1]. A 30 x 9 km rectangular geometry was created to simulate the icy shell. The ice shell is assumed to be a completely elastic shell of 9 km in total thickness, which was based on previous models created by colleagues, Rudolph et al. [2]. The models simulated a time in Europa's history where its cooling and thickening ice shell produced a stress regime that could form a 4km deep crack reaching the surface when the ice shell is 9 km thick. Our model places a 10 km wide and 1 km deep impact crater at the surface of the ice shell. The dimensions chosen were based on craters that have been observed on Europa [3]. A 3 kilometer deep and 3 meter wide fracture was then placed at the bottom of the crater. The crack width was calculated using the crack aspect ratio of 10^{-3} which determines the expected fracture width based on the behavior of cracks observed in terrestrial volcanic dikes [4,5]. Then, for a 3 km tall dike it gives a crack aspect ratio of 10^{-3} which indicates a dike width of 3 meters [1]. Model boundary conditions include that the bottom of the ice shell is fixed in all directions while the surface is free. The two vertical sides are fixed using a frictionless support so that the ice shell can only deform in the vertical direction at its boundaries.

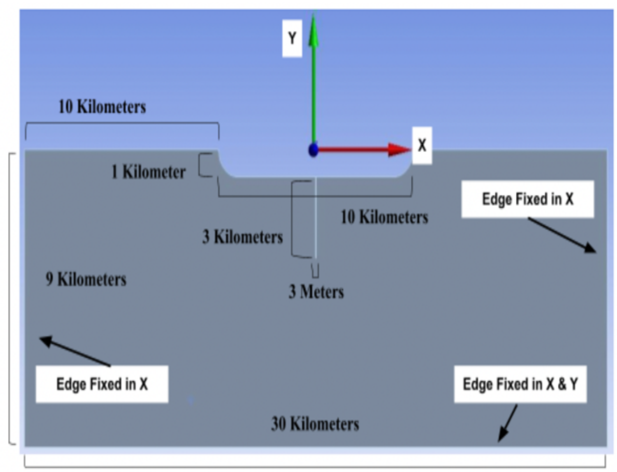

Figure 1. Base model setup: 30km x 9km 2 dimensional block representing the ice shell on Europa with left and right edges fixed in x, bottom fixed in all directions and the top free. A 10km wide and 1km deep impact crater is placed at Europa's surface, and a vertical fracture of 3km depth and 3m width extends from the base of the crater.

Once the geometry and boundary conditions were configured, a mesh was generated in order to study the impact of stresses on the ice shell. The area around the crater and fracture had a mesh with a higher resolution in order to allow for more precision when studying those stress areas. With the impact crater and 3 km fracture, a data file of initial stresses that correspond to the model conditions were imported. These values were based on analysis by [2] of the initial stresses that would be present for a 4km deep fracture from the original surface in a 9km ice shell. The radial and tangential stresses were also determined at various depths in the 9km ice shell. [2] Therefore in our model we specify the stress with equal values across the x-axis, but that vary with depth, according to [2]. The radial and tangential stresses were utilized to calculate the resulting shear stress. The radial stresses correspond to the x-direction, the tangential refers to the y-direction and the shear stresses are in the xy-direction.

Initial Results: The stresses were assigned to each of the nodes of the mesh, allowing the stresses to act on the present crater and crack (Figure 2). Ansys is then able to calculate the total deformation and normal stresses in both the x and y direction for the 9 km ice shell. Ansys is then able to calculate the total deformation and normal stresses in both the x and y direction for the 9 km ice shell.

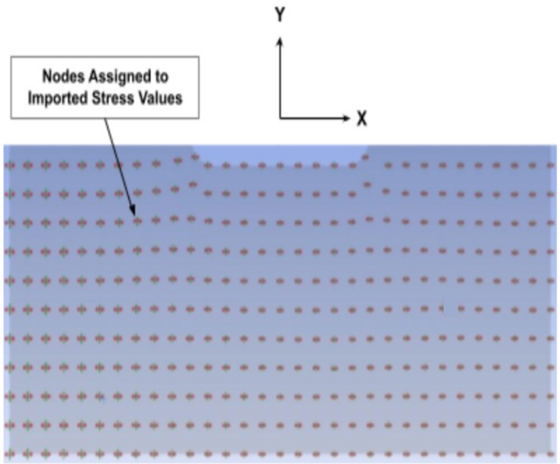

Figure 2. 2-Dimensional ice shell in Ansys mechanical after the mesh has been created and stresses from [2] were imported. Each node is assigned a stress value, with stress in y varying with depth according to [2].

Planned future work will explore the possible fluid intrusion of the crack, created by the fluid melt of an impact crater (Figure 3). Once the fracture is pressurized, more stress analysis can be run to see if there is any effect on the fracture or the surrounding surface. Ansys is able to produce the stress range present at various locations throughout the ice shell. By narrowing in on the stresses at the tip of the fracture, they can be analyzed to see if the fracture will be able to continue propagating. According to the theory on fracture mechanics a new fracture will be able to form or propagate if the tensile stresses present exceed the tensile strength of ice, 10^4-10^6 Pascals.

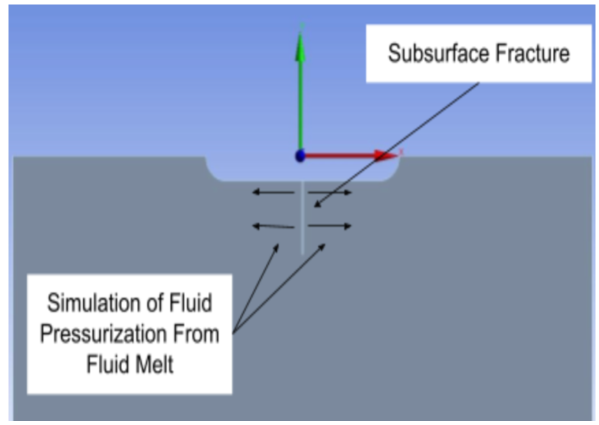

Figure 3. The pressurization of the subsurface fracture in Ansys simulates the pressure created by the entering and freezing of fluid melt that is produced by the impact.

Significance: This work will provide more insight into the behavior of fractures within the ice shell of Europa. They will also be able to give improved insight into fluid movement on the surface of Europa induced by impact craters. These results will be key in helping to better understand the behaviors of environments at Europa or at other icy ocean worlds, which can be beneficial when planning a mission to these bodies. For example, the upcoming Europa Clipper mission that is scheduled to launch in 2024 plans to orbit the moon for more than three years, while studying its icy shell and suspected internal ocean. The Europa Lander could follow and is planning to touch down on the ice in order to better investigate the possibility of life. Additionally, the general public is often fascinated by the possibilities of extraterrestrial life and have a general interest in how geological features may form on this moon. Even though these missions would give us a more accurate representation of the features and fracturing at Europa's surface, computer-generated models provide important insight into behaviors that are likely to occur under these conditions.

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References: [1] Craft et al. (2016) *Icarus, 274,* 297. [2] Rudolph et al. GRL, *in review.* [3] Turtle et al. (2001) *Science, 294,* 1326. [4] Pollard et all (1987), Sp. Paper 34, *Geological Association of Canada*, 5. [5] Broberg et al. (1999) *Academic Press,* 752.