FROM ORDER TO DISORDER: CHARACTERIZING THE TRANSITION FROM CRACKED TO COLLAPSE ON EUROPA. C. C. Walker[1] and B. E. Schmidt[1], [1]Georgia Institute of Technology, School of Earth and Atmospheric Sciences, 311 Ferst Drive, Atlanta, Georgia, USA 30332 (cat.walker@eas.gatech.edu; britneys@eas.gatech.edu).

Introduction: The observation of water plumes from the south pole of Enceladus [1] and the recent discovery of similar features on Europa [2] hint at ice penetrating fractures in the ice shells. The eruptions have been linked to tensile forces stemming from tidal effects that control the opening of the rifts [3, 4, 5]. The study of crack penetration is highly dependent on assumptions of ice shell thickness (and subsurface liquid water ocean), surface and interior stresses, and ice properties. The tidally-induced stress fields for Europa and Enceladus, specifically, have been studied in terms of their ability to adequately open rifts in order to a low for escape of subsurface material.

Both Enceladus' and Europa's surfaces are riddled with fractures, which betray a long history of geophysical activity. With an ~100 km deep ocean lying atop a silicate interior (e.g. [6], [7], [8]), Europa is an intriguing target for astrobiological study. Ice cycling may provide nutrients to the Europan ocean, and pores, basalcracks, and grain boundaries in its ice may serve as harbors for life. Such ice shell-ocean communication must occur over geologically short timescales in order for Europa to be habitable. One way in which this can occur is through disruption of the ice shell. Thus active geological areas have strong implications for the recycling of the ice shell, and the habitability of the ice shell itself.

Background: Recent work suggests that the process of formation of Europa's chaos terrain may include a collapse phase, and that the eventual appearance of the chaos terrain is determined in part by fracture density within the background terrain [10]. In studying the size distribution of fragments in Europa's chaos regions, it is possible to back out physical properties of the ice, such as material strength and cohesion properties and most importantly, energy necessary to create a fragmentation event using fragmentation theory. Fragmentation theory describes the breakage of a body into several pieces (e.g. [11]). Dynamic fragmentation modeling in elastic and plastic solids is primarily a statistical study of material behavior, and is categorized into three stages: (1) crack nucleation; (2) crack propagation; and (3) fragment coalescence.

Here, we use fracture density around Europa's chaos terrains and fragment sizes within the terrains to inform on chaos terrain formation. Using fracture density patterns at different locations around chaos terrains, we apply fractal theory to determine the fractal dimension of different regions. We use fragment size distributions within the chaos terrain to model fragmentation energy involved in the collapse event that formed the chaos.

Fractals and Fragments: We will use both fractal theory and fragmentation theory to understand regions surrounding chaos terrains.

Fractals. Fragmentation, or the breakup of a material into small parts ([11]), is a catastrophic phenomenon, often studied in its resulting state to understand the setting prior to the event. Turcotte (1986) showed that the fractal dimension is a measure of a natural material's resistance relative to the process causing fragmentation (stress), and as such, more fragile materials are expected to have smaller fractal dimension. With evidence of fractality, formation of natural cracks can be analyzed as a scale-invariant process. We apply the box-counting method to determine the fractal dimension of several regions around two different chaos terrains and analyze the distribution of cracks within those areas. The box counting method involves covering a digitized image (fracture pattern traces) with Euclidean sets of decreasing size, then computing the logarithmic density of the measure of these coverings. The fractal dimension is given then calculated based on these patterns.

Fragmentation. Based on bounded fragment distributions, [11] determined that the area disrupted by fragmentation is related to a material's wave speed. Based upon the derivation of local equilibrium at the fragment scale, the simplest model of fragmentation is applied here. Suppose a plate surface is subjected to force that is then converted to strain energy. This is, in turn, converted into fracture energy. In an elastic material, the volumetric potential energy will evolve with time. In this energy balance model, fragmentation occurs when potential energy of the material equals the fracture energy within the fracture network. Different patterns of fragmentation can produce different estimates of material properties and the energy required to produce the fragmentation event, examples of which are shown in Fig. 1 and defined in [11]. A characteristic length scale is based on the local balance of kinetic and fracture energy and layout of fragments. In this theory, we consider a body to break apart into a certain collection of fragments. Each fragment takes kinetic energy as the object breaks up, and this energy goes into local expansion and rigid-body motion. Local kinetic energy then contributes to further failure. A characteristic length scale for fragmentation is based on the energy balance of potential, kinetic, and fracture energies in a given material [11]. Thus, [11] determined the energy driving fragmentation in two dimensions based on material density, strain rate, surface energy, propagation speed, and fracture toughness. We used the simple statistical model [11] to test the use of fragmentation theory on collapse features. Using published fragment size data from the Val Pola rock avalanche [15], we determined the energy driving the event to be approximately 1.5 kJ/kg, in agreement with previous estimates and measurements. Hence, we will present our estimate of the energy released in chaos terrain collapse through application of fragmentation theory and iceberg capsize analysis, in addition to determining time-to-fragmentation (formation time).

Comparing these results with our results from the fractal portion of the study, we seek to present a "tipping point" of fracture densities and a map of stress response around chaos terrains. This study's approach has already been successfully applied to the Helheim Glacier in Greenland as well, results from which we will present for comparison.

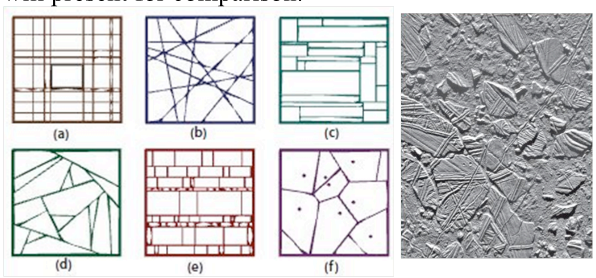

Figure 1. Right: Common geometric fragmentation patterns, picture from [9]; Left: PIA01403 – chaos region on Europa taken by Galileo in 1998; (a) Random lines of equal length; (b) Pickup Sticks/Mott fragmentation; (c) Sequential Segmentation; (d) Same as (c) with conditions on shortest dimension; (e) Randomly distributed/oriented segments; (f) Voronoi- Dirichlet fragmentation. Each type is associated with specific length scales and fragmentation types.

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