INVESTIGATING ACTIVE CHAOS FORMATION AS THE SOURCE OF EUROPA'S WATER VAPOR PLUMES. C. C. Walker[1] and B. E. Schmidt[2], [1]NASA Jet Propulsion Laboratory, 4800 Oak Grove Dr., Pasadena, CA 91109, USA (catherine.c.walker@jpl.nasa.gov), [2]Georgia Institute of Technology, 311 Ferst Dr., Atlanta, GA 30332, USA (britneys@eas.gatech.edu).

Introduction: Recent observations using two different detection techniques have shown that water vapour plumes may be erupting from the surface of Europa [1, 2, 3]. The source for the initial plume detection was suggested to be long surface fractures in the area of interest [1], the opening of which would be controlled by tidal stress, similar in fashion to the tiger stripes of Enceladus [4, 5]. However, tensile fractures that penetrate all the way from the surface to the subsurface ocean remain unproven. It is likely that the putative plumes emanate from geologically active regions; one type of terrain suggested as recently/currently active is chaos terrain [6]. The likelihood that shallow water [6, 7] underlies these young surface features, and is involved in their formation, inspires our inquiry into whether or not the observed plume activity is produced via chaos formation and evolution.

Background: The youngest features found thus far on Europa are its ubiquitous chaos terrains, overlying and interrupting features such as fractures and ridges. They are thought to form above shallow water lenses, following melting in near-surface regions of the ice shell. While most are found in the mid-to-low latitudes, chaos terrains are spatially distributed around the moon. It has been suggested that the eventual appearance of the varied chaos terrains is determined at least in part by the pre-existing fracture density of the localized background terrain [6]. It is likely that their formation involves a surface deformation phase, and the eventual collapse of the ice lid into the forming melt lens along with potentially violent mixing upon its rupture [6, 7]. These processes are likely analogous to phenomena observed during the calving and collapse of terrestrial ice shelves (see next section).

The possibility that active cryovolcanism and plumes could be present on Europa has been considered previously [8, 9] to explain the existence of low-albedo surface features. In that work, the greatest height expected for modeled Europa plumes was ~100 km, with eruption velocities of ~600 m/s for gas-dominated plumes; heights between 1-25 km for more realistic values of plume composition. Initial observations of the putative plumes [1] suggested heights of ~200 km and eruption velocities of ~700 m/s, which would require surface temperatures of over 130 K above Europa's ~100 K mean surface temperature. The amounts of water implied by each of the observations were similar in magnitude. The locations attributed to the plume sources lend themselves to the notion that they are not tied to a single location on the surface. Two observations from 2014 occurred at a similar latitude to the 2012 observation, though at different sub-longitude points; the third 2014 observation was located at a location closer to the equator, near Pwyll crater, as was the 2016 detection [3]. The expectation that the activity correlated with orbital location was determined to be invalid [2]; it has since been suggested that the plumes may be transient phenomena. However, the possibility that smaller plumes are tidally-modulated (~10s of km) has been suggested [10]. Such smaller-scale plumes have been postulated to be the source of dark deposits along some of Europa's lineaments, margins of some chaos terrains, etc. [8, 9, 11].

Figure 1. Snapshot from video of Jakobshavn glacier, where basal fractures lead to detachment of icebergs (top) and their capsize, which causes icy material and water from be-low to be ejected into the air (bottom). Credit: Jason Amundson, U. of Alaska Fairbanks.

Approach: We argue that the geological and hydrodynamical processes associated with chaos formation, their global spatial distribution, and timescales over which their formation occurs, match better with observed plume activity than when considered to be related to tidally-controlled through-ice shell rifts.

On Earth, deformation of an ice lid or "roof" over a water-filled cavity can be caused by overpressure in–or withdrawal of–a fluid encapsulated in the subsurface, due to an overloading or absence of hydrostatic support leading to subsurface fracture propagation at the base of the lid [e.g., 12, 13]. Once structral integrity of the lid is sufficiently lowered due to damage, water in the subsurface cavity may drive fractures further upwards and cause a rupture of the lid. Of course, whether or not the cavity is over- or under-pressurized to begin makes a difference in the resulting topography. On Earth, where the ice lid-to-cavity ratio is large, i.e., relatively close to the surface, basal breakup leads to catastrophic collapse of the lid. Terrestrial observations of such events in ice-over-water systems have shown that water and icy material is churned up and ejected during the process. While trajectories of such water and icy bits in terrestrial events are small, consideration of differences between surface gravities and atmospheres of Earth and Europa alludes to the producibility of significant material plumes at the latter. We suggest that there are two phases within the process of chaos formation that may be capable of producing such large “clouds” of material: (1) initial breach or rupture of the surface, during which the subsurface water pocket is “popped” by mechanical failure of the overlying lid; and (2) following initial lid fragmentation, “icebergs” developed during formation capsize and launch particles into the atmosphere.

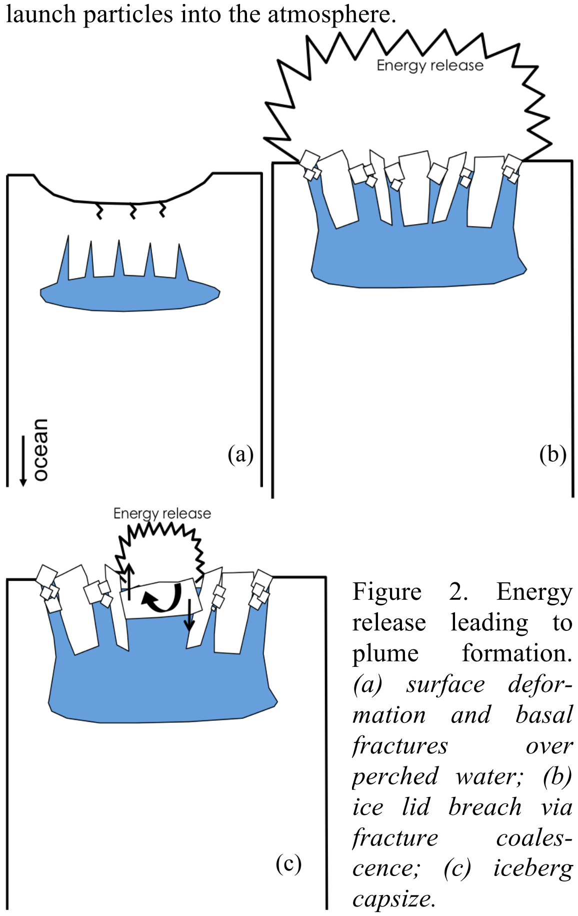

Figure 2. Energy release leading to plume formation. *(a) surface deformation and basal fractures over perched water; (b) ice lid breach via fracture coalescence; (c) iceberg capsize.*

To estimate how such processes could produce an observable plume event, we must understand the system geometry and energy contained in it.

Methods: To examine the possible energy scenarios, we use (1) observations of Europa’s surface and geometry of chaos terrains by Galileo, (2) analytical models of fragmentation energy release, and (3) a numerical model that represents ice as a matrix of closely packed, bonded circular particles that interact through elastic-frictional forces [7, 14].

Observations of chaos terrain are used to determine energy required to create a given size distribution of fragments, using fragmentation theory. Here we use the Grady energy balance model, based upon the derivation of local energy equilibrium at the fragment scale. For example, the energy required to produce the average fragment size in Conamara chaos is 0.05 – 0.35 J/m, dependent upon an assumption of yield strength. This energy is transmitted into the water below; depending on assumed energy transfer efficiency, resultant plume heights can reach between 10-150 km.

When a large iceberg formed during rupture capsizes, energy is again transferred into the water and icy matrix material. Capsize energy can be calculated as:

$$PE_{i+w} = \rho_i g\, H^3\, \varepsilon(\varepsilon-1)\,(1-\rho_i/\rho_w)/2\,. \qquad (1)$$

Here, ρ_i and ρ_w are ice density, g is acceleration due to gravity, H is initial iceberg thickness, and ε is the ratio of initial iceberg width to thickness. Dependent upon assumed values, capsize can produce “splash” plumes on the order of 10s of km.

Results: In this study, we explore two end members of the likely source events: first, the expulsion of overpressurized water through basal fracture propagation and roof collapse; second, we assess the effects of secondary iceberg overturn/capsize on water motion in the near-surface. We will show the limitations of cavity shape and size on the likelihood of observable plume creation. Both size and shape of the cavity, in addition to its location within the ice shell (depth of “roof”), have effects on the energy of the system, which in turn places limitations on the energy available for fracture propagation and water expulsion through cracks and iceberg capsize.

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