COMPARISON BETWEEN TERRESTRIAL EXPLOSION CRATER MORPHOLOGY IN FLOATING ICE AND EUROPAN CHAOS. S. E. Billings and S. A. Kattenhorn, Department of Geological Sciences, University of Idaho, Moscow ID 83844-3022. (sandib@uidaho.edu)

Introduction: Craters created by explosives have been found to serve as valuable analogs to impact craters, within limits [1, 2]. Explosion craters have been created in floating terrestrial ice in experiments related to clearing ice from waterways [3–6].

Features called "chaos" occur on the surface of Europa's floating ice shell [7]. Chaos is defined as a region in which the background plains have been disrupted [8–13]. Common features of chaos include rafted blocks of pre-existing terrain suspended in a matrix of smooth or hummocky material; low surface albedo; and structural control on chaos outline shape by pre-existing lineaments [8–10, 12].

All published models of chaos formation call on endogenic processes [8–13] whereby chaos forms through thermal processes. Nonetheless, we note morphological similarities between terrestrial explosion craters and Europan chaos at a range of scales and consider whether some chaos may have formed by impact. We explore these similarities through geologic and morphologic mapping.

Terrestrial Explosion Craters on Floating Ice: Explosion craters on floating terrestrial ice have been reported in studies aimed at determining optimum configurations for clearing ice. Images and morphological descriptions of the resulting craters are included in many of the reported experiments [3–6]. We have selected images for analysis based on image quality and depth-of-charge.

These craters are on the order of a meter in diameter. Crater morphology varies from open holes with debris floating in the hole and/or scattered around the hole (Fig. 1a) to a simple ice breakage pattern of radial and concentric cracks (Fig. 1b).

Morphologic Mapping: We mapped regions of chaos on Europa and explosion craters in floating ice on Earth (Figures 1a–d). Because chaos is typically not considered to be related to cratering [8, 11], the terminology describing morphologically similar features is often different. In such cases, we use both the cratering name and the chaos name to describe mapped features: smooth matrix/open water; blocky matrix/floating ice chunks; halos/smooth ejecta; and massifs/ejected blocks.

Discussion: The scale of the terrestrial craters is an order of magnitude smaller than the chaos features shown, and two or more orders of magnitude smaller than major Europan chaos. Otherwise, the explosion craters and chaos regions exhibit similar features and general morphology. They exhibit quasi-circular shape with an internal smooth to blocky matrix, in which rafts or blocks may be suspended. Halos, cracks, or blocks of material may surround the holes.

If Europa has experienced thickening of the ice crust over time [9, 14], then crater morphology would be expected to change with time and with crustal thickening [15]. Observations of relative ages of crater type and chaos types [16] are consistent with the concept of a thickening ice lithosphere that results in changes in crater morphology from open holes with broken edges (perhaps analogous to chaos) to macula (e.g., Tyre) to central-peak (e.g., Pwyll) and bowl-shaped craters [15].

It has been noted that chaos size distribution matches cratering populations [14]. It is not clear whether geographical distribution of chaos [9, 10, 16, 17] is consistent with cratering distributions and morphologies for a crust with varying thickness [7].

Chaos shape may be the most difficult to explain if an argument is made that some chaos regions formed by impact. Structural controls by pre-existing lineaments is common, however, which should affect impact-induced craters in much the same manner as melt- or diapir-induced chaos [8, 10]. Other questions that need to be addressed for a comprehensive evaluation of a potential relationship between chaos and impact are: How does scale affect the analogy of terrestrial craters and Europan chaos?; What is the relationship of impact-induced chaos to other features, such as spots and domes?; How would heat input during impact affect local melting and local diapirism?

Analysis: Breaking an Ice Layer by Wave Flexing: The creation of craters by impact can create tsunami-like waves radiating out from the impact site [1, 15], which break the crust as they travel outward. The ice layer will break due to upward flexure if the bending stress exceeds the tensile strength of the ice crust at its base; breakage will occur at a distance $x_{\square}$ from the maximum displacement, $x_{\square}=\pi\square/4$, where $\square= [Eh^3/(3\square g(1-\square^2))]^{1/4}$ [18]. Thickness of the crust is h; elastic parameters of the crust are Young's modulus, E, and Poisson's ratio, $\square$; density of the ice layer is $\square$; gravitational acceleration is g; and the wave height is w_o. As calculated from [18, 19], maximum bending stresses are $\square_{max}=-w_o Ehe^{-x/\square}\sin(x/a)/(\square^2(1-\square))$.

We used a simplified model to establish to a first approximation the ability of impact-induced waves to break the Europan crust into fragments or rafts, such as those observed in regions of chaos (Fig. 1c, d). We find that a wave of amplitude 1 km is able to break a 6 km-thick Europan ice layer. This wave height is of the same order as calculated terrestrial ocean wave heights of 4 km resulting from typical impact [20]. A 6 km thick layer would break at a distance 13.6 km from the open edge, creating pieces of that dimension. This is consistent with raft dimensions of up to 20 km in Conamara Chaos [11].

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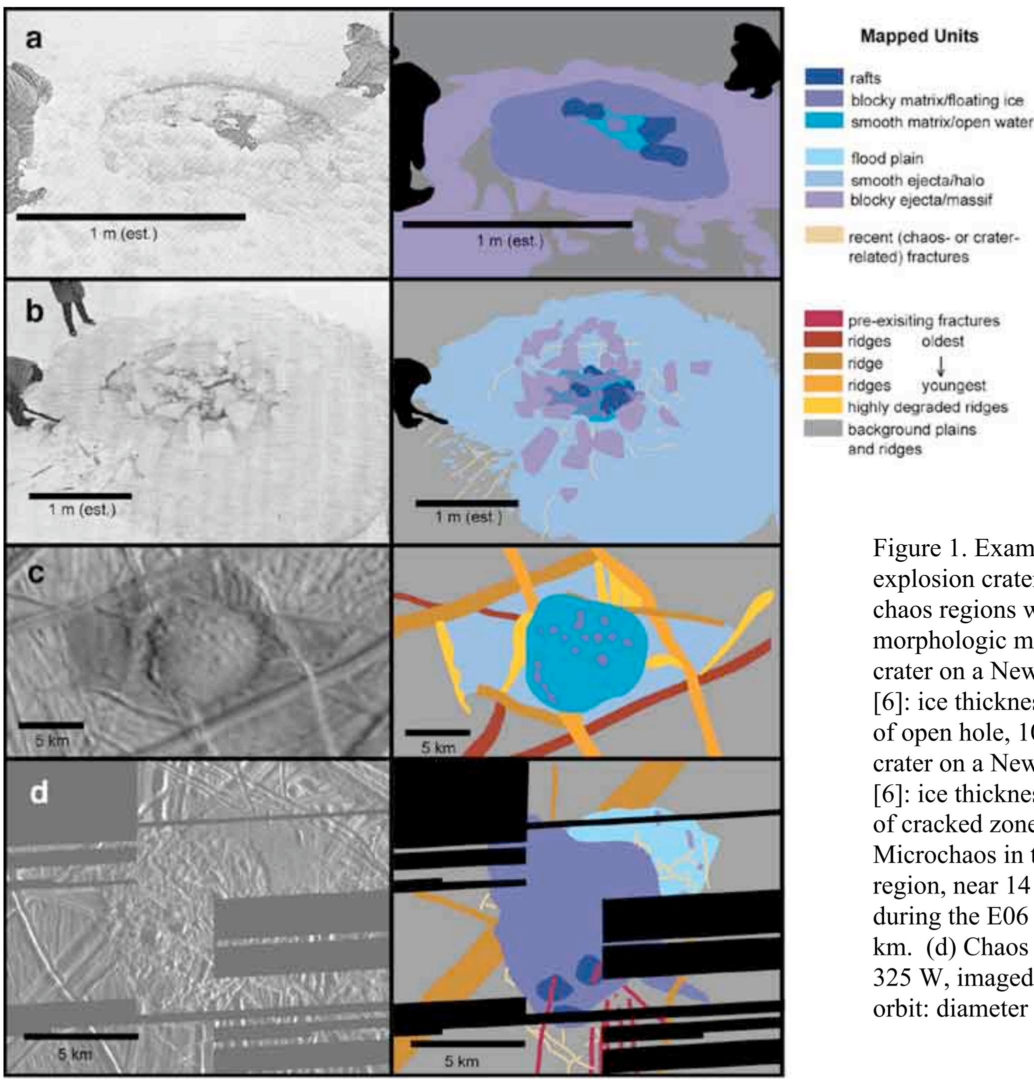

Figure 1. Examples of terrestrial explosion craters and Europan chaos regions with corresponding morphologic maps. (a) Explosion crater on a New Hampshire lake [6]: ice thickness 16 in, diameter of open hole, 105 ft. (b) Explosion crater on a New Hampshire lake [6]: ice thickness 18.5 in, diameter of cracked zone, 14.4 ft. (c) Microchaos in the Conamara region, near 14 N, 273 W, imaged during the E06 orbit: diameter ~10 km. (d) Chaos region near 5 N, 325 W, imaged during the E04 orbit: diameter ~7.5 km.