NUMERICAL SIMULATIONS OF IMPACTOR PENETRATION INTO ICE-OVER-WATER TARGETS.

L. Ong[1], G. Gisler, R. Weaver, and M. Gittings[2], [1]Los Alamos National Laboratory, Los Alamos, NM 87545; ong@lanl.gov, [2]Science Applications International Corporation, 10260 Campus Point Drive, San Diego, CA 92121.

Introduction: Only 28 impact features with diameters greater than 4 kilometers have been identified on Europa, the largest with a diameter of 43-44 km [1]. While craters with low diameters follow classical morphologies observed on other planets, two craters with diameters larger than 30 km have unusual morphologies comprising a smooth central region surrounded by concentric ring massifs. These multi-ring features suggest that Europa's 80-170 km thick H_20 layer [2] is composed of a brittle ice layer overlying ductile ice [e.g. 3] or a liquid ocean [4]. Estimates for Europa's crustal thickness range from two km [5] to 30 km [6], and no consensus has been reached.

Numerical simulations of impacts into ice layers overlying liquid water performed by Turtle and Pierazzo [7] have placed a lower-limit of three to four km for the ice thickness by reproducing craters with classical morphologies formed completely within the brittle ice layer. Impacts in which melting and vaporization allowed a liquid ocean to seep to the surface were modeled to discover conditions that prevent classical crater formation.

The paucity of Europan craters is attributed to resurfacing events resulting in a geologically young surface [1]. No features on Europa's surface, however, have been interpreted as a record of crust-penetration impacts, but the possibility is strong that such features exist [8]. Because of the uncertainty regarding impact velocity distributions, impactor masses, and consequently impact energies, no upper bound for impacts on Europa is known. Impact features representing penetration through Europa's brittle surface have yet to be observed or proposed.

Laboratory impact experiments into two-layer ice over water targets were conducted by Ong *et al.* [10] to explore morphologies of impactor penetration features. This was the first laboratory experiment to investigate impacts into layered ice targets, although ice-on-solid-ice experiments had been performed [e.g. 11]. The experiments produced classical crater morphologies in addition to two distinct penetration morphologies as a function of ice thickness, ice strength, and impact energy. In this study, a comparison of these results with numerical simulations of both laboratory- and Europa-scale impacts into ice-over-water targets allows further exploration of the morphologies of such impacts and their possible surface record on Europa.

Modeling: Two-dimensional vertical impacts of ice projectiles into ice-over-water targets were modeled using the continuous adaptive mesh Eulerian code RAGE, jointly developed by Los Alamos National Laboratory and Science Applications International Corporation (SAIC). The Pactech/SAIC equation of state was used for water, which includes many of the relevant ice phases and a good vapor dome. The strength parameters for ice were obtained from Pittenger *et al.* [12] and used in the simple elastic-plastic yield model with tensile failure that is standard in RAGE.

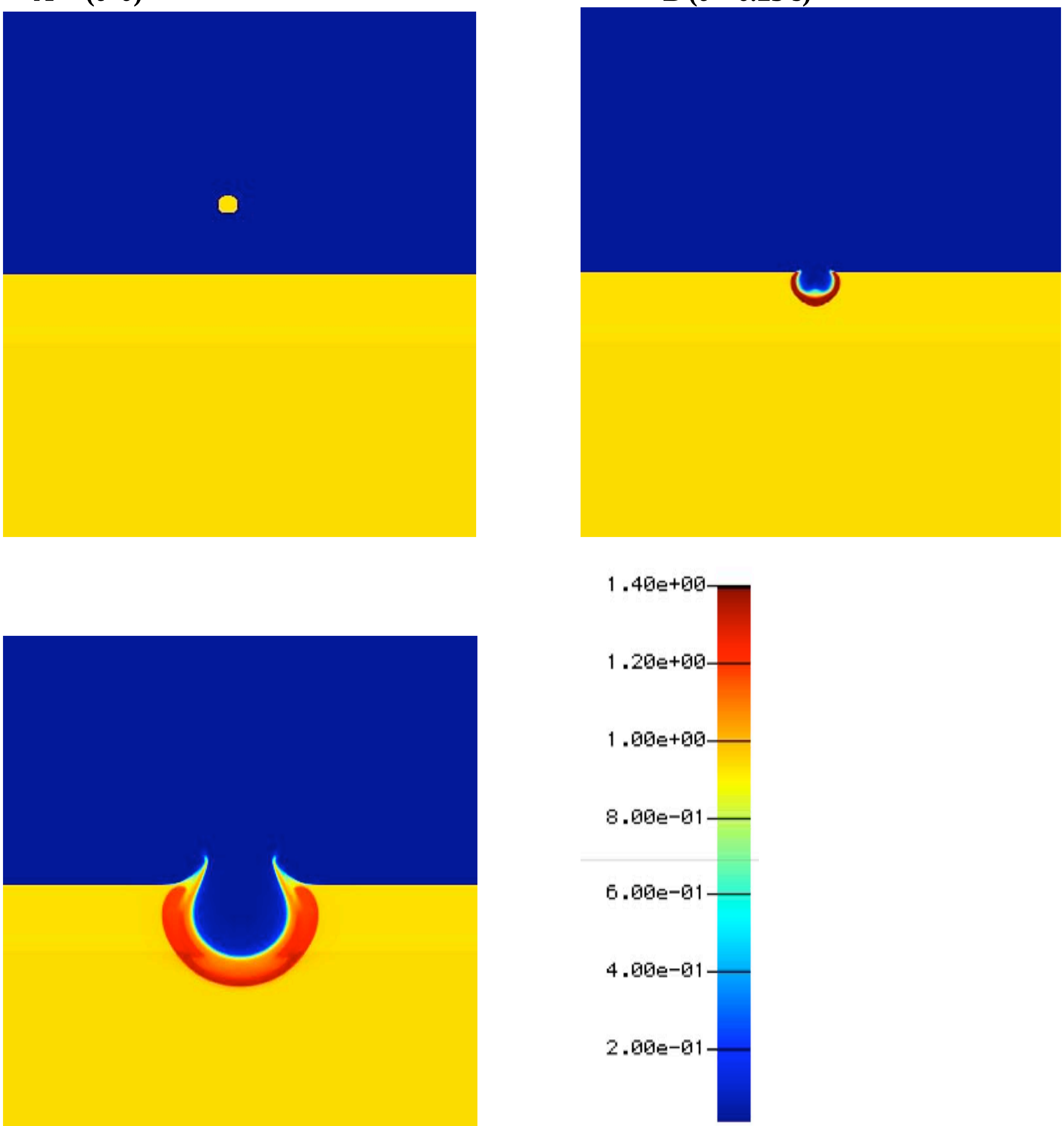
For laboratory-scale simulations, the targets were composed of a solid ice plate of varying thickness above a 10-cm thick water layer. The water was held at 0° C, and the ice layer, ice projectile, and surrounding atmosphere had temperatures of -10° C. Impactor velocity was varied from 100 m/s to 400 m/s. Environmental conditions were set to those on Earth, with pressure at 1 atmosphere. Because of the strength-dominated nature of laboratory-scale impacts, gravity was not included the model.

In Europa-scale simulations, the targets comprised a solid conductive water-ice layer with variable thickness overlying a liquid water layer. The ice layer has a linear thermal gradient with temperatures from 110 K at the surface of the ice layer to 270 K at the base of the ice layer. Atmospheric temperature followed a linear gradient from 110 K to 60 K. Europa's surface gravity of 1.3 m/s2 was also factored into the Europa-scale simulations. Spherical ice projectiles were impacted into the layered targets at 26.5 km/s, the median impact velocity for Europan impactors. Figure 1 illustrates material densities at three stages of a penetration impact at Europan scales. While at initial contact (fig. 1b) the target structure does not differ from solid ice, the ice-water interface is made clear by the high-density shock wave boundary.

Conclusions: Comparisons between laboratory experiments and numerical simulations are useful both in code validation and in linking the two methodologies. Numerical models incorporating ice fragmentation will allow further comparisons between experiments, models, and observations of the Europan surface. The investigation of impactor penetration into the Europan subsurface will be greatly aided by simulations incorporating fragmentation and illustrating the possible surface record of such an impact.

References: [1] Moore J.M. *et al.* (2001) *Icarus, 151*, 93-111. [2] Anderson J.D. *et al.* (1998) *Science, 281*, 2019-2022. [3] Pappalardo R. *et al.* (1998) *JGR, 104*, 365-368. [4] Greenberg R. *et al.* (1998) *Icarus, 135,* 64-78. [5] Carr M.H. and Belton M.J.S. (1998) *nature, 391*, 363-365. [6] Ojakangas G.W. and Stevenson D.J. (1989) *Icarus, 81*, 220-241. [7] Turtle E.P. and Pierazzo E. (2001) *Science, 294*, 1326-1328. [8] Kadel S.D. and Greeley R. (2000) *LPSC XXIX*, #2091. [10] Ong L. *et al.* (2004). *GSA Abstracts with Programs 2004*, # 56-1. [11] Arakawa M. (1999) *Icarus, 142,* 35-45. [12] Pittenger B. *et al.* (1998) *J. Vac. Sci. Tehcnol., A16,* 1832-1837

A (t=0) **B (t = 0.25 s)**



C (t = 1.5 s)

Figure 1: Density (g/cm3) cross-section of Europa-scale impact into ice-over-water target. The ice layer is four km thick, overlying 11 km of water. The projectile begins at an altitude of 4 km.