BEHAVIOR OF LOKI PATERA, IO REVEALED THROUGH MATHEMATICAL AND LABORATORY MODELING. Jennifer A. Lougen[1], Tracy K. P. Gregg[1], and Rosaly Lopes[2]. [1]Department of Geology, 876 Natural Science Complex, University at Buffalo, Buffalo, NY 14260-3050; tel. (716) 645-6800 x. 2462, email: jlougen@buffalo.edu, [2]Jet Propulsion Laboratory, California Institute of Technology, Mail Stop 183-601, 4800 Oak Grove Drive, Pasadena, CA 91109

Introduction: Loki Patera, Io (Figure 1) (12.7°N, 51°E) is a depression about 180 km across and is a thermal anomaly that at times generates up to 15% of Io's total heat flux [1]. Loki Patera displayed periodic behavior between 1983 and 1997 [2], expressed as thermal anomalies moving across its surface according to Near Infrared Mapping Spectrometer (NIMS; figure 2) data. Of the 540-day periodicity observed at Loki Patera only 230 days are interpreted to be volcanically active [2]. Debate exists as to whether this behavior represents repeated surface flows of lava, or a regularly overturning lava lake [3, 4]. We present preliminary results from numerical modeling and laboratory simulations to test these hypotheses. Active lava lakes on Earth require an actively convecting volume of magma that is directly connected to a deeper magma source [5]; we use this definition in our models.

Experimental Models: The experimental tank that we used to model the behavior of Loki Patera is Plexiglas, 30 cm x 30 cm x 31 cm and has 5 vent holes (1 cm diameter) on the tank floor. Four vents are located near the corners of the tank, and 1 is located in the center of the tank, similar to a 5-value die face. Each vent can be turned on and off, and has a plug that is placed over the hole on the tank floor when that particular vent is not being used. Almost 4 L of light corn syrup is used in each experiment and is heated up to a temperature between 39°C - 44°C in a bucket using a copper coil with hot water (~48°C) running through it. At these temperatures, the viscosity of the corn syrup is 12.2 - 9.4 Pa s, respectively. The corn syrup is then pumped into the tank at an effusion rate between 1.1 - 1.3 mL/s. Thus, experimental duration is 1 - 2 hours, depending on effusion rate.

Most of the experiments completed so far have shown that the corn syrup advances across the floor in a concentric manner regardless of vent location. Rarely, corn syrup advances across the tank floor irregularly and unevenly; this may be due to any residual water that was unable to be drained from the system prior to the experiment. Once a depth of about 2 cm has been obtained in the tank food color is added (yellow, green, red,in that order) and the different colors are observed to advance in elongate, lobate "fingers" beneath the prior color, and form a temperature gradient. In other words, the first material erupted remains near the surface throughout the experiment. These fingers flow downward once they reach the walls of the tank (Figure 3) that act as a boundary (to limit movement of corn syrup). At the vent, the colors of corn syrup injected come out in what looks like a plume.

A crust, or "skin," forms quickly after the injection of corn syrup into the tank. The crust forms folds and cracks due to compression along the edges of the tank resulting in the crust folding into the tank walls. Cracks crosscut each other (Figure 4), but the experiments have yet to show corn syrup being brought to the surface from these cracks (i.e., colors are not surfacing).

We observed a convection cell in one simulation (Figure 5) that formed near the vent and looked like an eye when viewed from the side. Why this formed in this experiment and not the others is not yet known. Towards the end of most of the experiments many individual fingers flowed downward at the walls of the tank and start descending from many areas of the red colored plume. This is different than the yellow and green colored plumes where only a few fingers flowed down the tank walls and they are much larger in size. This may be due to instabilities created within the lake due to the formation of the temperature gradient and instabilities created within the yellow and green plumes.

Magma Production Rates: Assuming that the diameter of Loki Patera is about 180 km and the "island" diameter is about 90 km, production rates for Loki Patera can be calculated using:

$$M = V_{patera} - V_{island} / (540 \text{ days OR } 230 \text{ days})$$

where V is volume [2]. Modeling Loki Patera and the "island" as a cylinder, these production rates can help in determining a magma chamber size and possible geometry. The production rates calculated that seem most reasonable correspond to a volume of magma with a depth between 70 m – 150 m. These depths correspond well with thermal models relating solidification time the amount of active days observed at Loki Patera. Magma production rates vary from 7,700 km^3/yr - 16,500 km^3/yr with a 230 day periodicity to 3300 km^3/yr - 7000 km^3/yr with a 540 day periodicity. On Earth, the average annual production rate is 2 - 8 km^3/yr. This represents <8.7 x 10^{-9}% of Earth's mantle erupted per year, whereas using the above production rates for Loki Patera between 1.0 x 10^{-4} - 3.0 x 10^{-4}% is erupted annually. This may seem high but over a

16 year period of observations from Loki Patera, only 2.0 x 10^{-3}% of Io's mantle is erupted. Using these production rates for the various depths and active days, a spherical magma chamber will have a radius between 19 km - 34 km. A cylindrical magma chamber will have a radius between 144 km - 324 km. A conical magma chamber will have a radius between 250 km - 560 km. The sizes of the differing magma chambers takes into account that the magma chambers will not be thicker than Io's lithosphere (~30 km) [6].

Future Work: More experimental modeling needs to be completed, using polyethelyne glycol wax instead of corn syrup to investigat a broader range of rheologies. We will also use multiple vents in a single simulation to investigate the significance of vent geometry.

References: [1] Spencer et al. (2000) Science vol. 288 no. 5469, 1198-1201. [2] Rathbun, J.A. (2005) LPS XXXVI abs. no. 1981. [3] Davies, A.G. (1996) Icarus 124, 45-61. [4] Davies, A.G. (2003) Geophysical Research Letters, vol. 30, no. 21. [5] Harris, et al. (1999) JGR vol. 104 no. B4, 7117-7136. [6] Keszthelyi, L. et al. (2004) Icarus 169, 271-286.

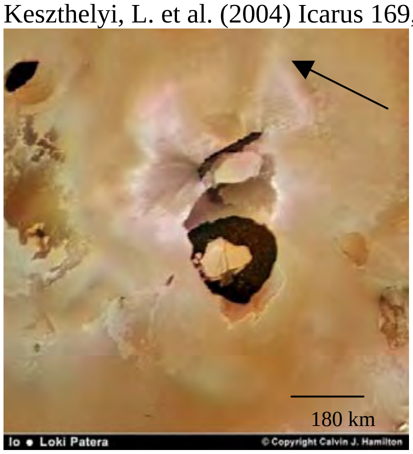

Figure 1: Loki Patera (Voyager, NASA image PIA000315). Arrow points North.

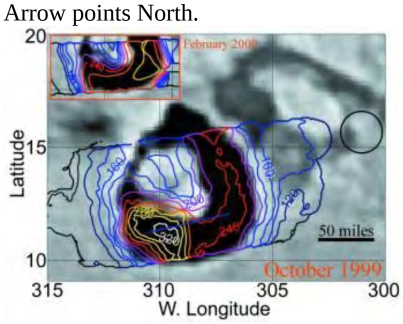

Figure 2: NIMS data (Galileo, NASA image PIA02549). Whites and yellows "hot" (320 K and 280 K), blues "cold" (160 K). Shows surface temperature progression from the SW corner towards the NE corner of Loki Patera between October 1999 and February 2000 (inset).

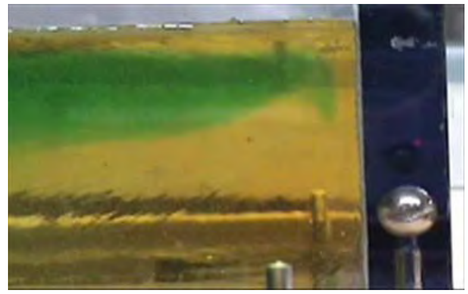

Figure 3: Side image taken to the right of vent (corner). The formation of a temperature can be seen between the yellow and green colored corn. The temperature of the fresh corn syrup is 40.5°C.

Figure 4: Image of skin formed on corn syrup almost immediately after pumped into tank. The vent location is in the diagonally opposite corner to this vent with cap shown in image. In upper left corner of image can see where skin has formed tension with the tank wall. The middle portion of image shows folding of corn syrup skin. For scale, the plug is 1 cm in diameter.

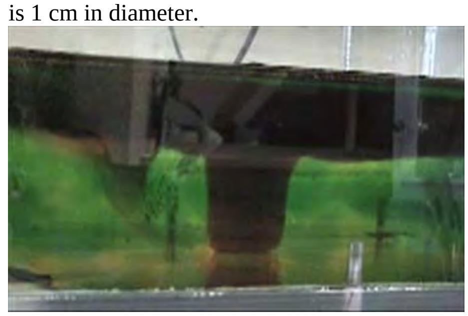

Figure 5: Image of convection cell formed in tank experiments. Side view of tank; dark area near image center is the plume generated over the active vent-, corn syrup depth here is about 9 cm. Yellow can be seen along the floor of the tank. Green can be seen in the middle; notice the blotchy appearance. This is due to different fingers of green corn syrup wrapping down along the walls of the tank. The red corn syrup is the plume. To the left of the red column a green eye shaped feature can be seen pulling down an arm of red corn syrup from the plume back into the column, this is the convection cell. The temperature of the fresh corn syrup is 43°C. The effusion rate is about 1.3 mL/s and is being pumped out from the middle vent.