A MODEL FOR THE FORMATION OF PATERAE ON IO. Jani Radebaugh[1] [1]Planetary Image Research Laboratory, Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, 85721, jani@LPL.arizona.edu

Introduction: Paterae on Io are similar to calderas on the Earth and other planets, yet they have some differences, such as their great sizes (from 2 to 206 km diameter) and lack of high edifices. Tidal heating from Jupiter leads to the production of molten material and the eruption of large amounts of mafic to ultramafic lava within Io's paterae, as well as across its surface. Formation of paterae is likely also different from our understood models of caldera formation, as the process must lead to the unique morphologies of the features we observe. I describe a possible model for the formation of a typical patera, which uses our collective observations of Io's paterae and current understanding of Io's interior as the basis for the steps in the model.

I. Mantle heating and convection lead to upwelling of diapirs that impinge on the base of the crust.

Heating and convection occur primarily in Io's asthenosphere, a 50 – 100 km thick layer that is probably not permeable to convection with lower mantle materials (Fig. 1). These assumptions are based on modeling by Tackley and others [1, 2] that correlates concentration of diapirs with volcanic centers on Io's surface (clustered preferentially at sub- and anti-Jovian points [3, 4]). Diapirs are spaced at most several hundred kilometers apart, if a single diapir feeds a single volcanic center (Fig. 1).

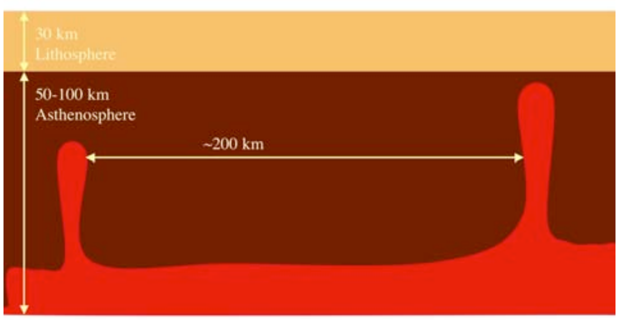

Figure 1. Model convection in Io's asthenosphere. ~200 km spacing between diapirs is related to spacing between volcanic centers.

II. Magma rises through the crust, through diapirs (Fig 2a), pipes (Fig 2b), or small packets that feed magma chambers (Fig 2c).

The crust is cold, due to rapid burial from resurfacing [5], on average 30 km thick, and highly fractured from mountain building and tidal action [6]. This makes it difficult for diapiric rise (Fig. 2a), unless there is a substantial amount of stoping of overlying materials into the diapir.

Magma rising via a pipe would be strongly connected to the mantle (Fig. 2b). This scenario explains the high temperatures (since material has not differentiated substantially from mantle compositions) and extremely high magma supply rates at many paterae [6]. However, cracks that act as magma pathways become sealed up quickly due to overburden pressure. Perhaps it is better to consider a dike, possibly extending the depth of the crust, as has been modeled by Leone and Wilson [7], which is open temporarily.

Magma could rise in small packets along cracks or dikes and feed a sequence of magma chambers in the crust (Fig. 2c). It is important to maintain low magma chamber residency times and high magma supply rates, in order to avoid cooling and differentiation, since we see no evidence of evolved materials on Io's surface.

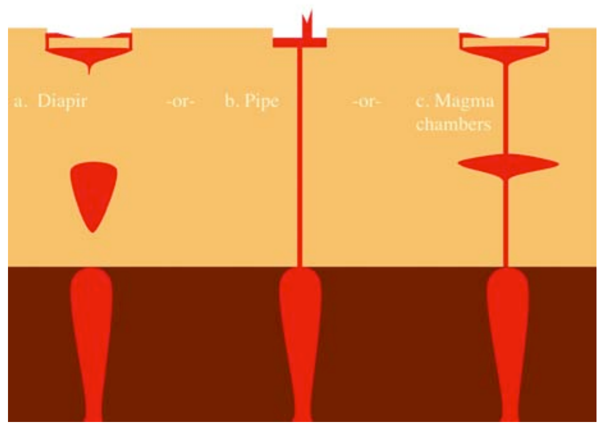

Figure 2. Three scenarios for magma rise through Io's crust.

The viability of each of these scenarios depends upon the tectonic constraints mentioned above and magma supply rates, in which Fig 2b requires higher rates than Fig 2a or c. Material compositions and rheologies are also important, and these will be discussed in terms of how they affect the separate scenarios.

III. Magma finds a high-level zone of neutral buoyancy. Then it:

a. Erupts in a lava flow field, or

b. Spreads laterally to form a small chamber of 5-40 km in diameter, a few kilometers below the surface.

If the zone of neutral buoyancy is at the surface, lava will erupt without forming a small, subsurface, magma chamber. This may have happened at such locations as Sobo Fluctus, which occupies a depression [8]. The 5-40 km chamber size is determined by the modal patera diameter, so it therefore represents the precursor to a "typical"-sized patera [4].

IV. The overlying crust, weakened by fracturing and interlayering of volatiles, collapses over the magma chamber.

For terrestrial calderas, this happens when some amount of magma has evacuated the chamber. The same could be true on Io, although magma can leave the chamber both through eruption or withdrawal into the source region. Alternatively, the mere presence of hot magma underneath already weakened and volatile-rich crust may trigger stoping of material into the patera [9].

V. The small patera (5-40 km diameter) that formed from collapse of the magma chamber evolves in one, or a combination, of three ways:
a. No eruptions occur, magma supply shuts off, and the patera is "dead"
b. Lava fills the patera (sometimes to overflowing) and continues to erupt as a lava lake connected to its source
c. Lava escapes at the margins of the patera, leading to eruptions across its floor, and the magma chamber grows and evolves laterally, leading to enlargement of the patera.

There are several paterae in the 5-40 km diameter range that are probably actively erupting lava lakes. Pele Patera has been described as a highly confined, active, lava lake [6,10,11]. Magma is supplied to this volcano at a high rate, but must also be recycled, as there is little evidence for overflows, despite the continuous, high, thermal output.

Lateral spreading of magma chambers could lead to the formation of large, active paterae with multiple overlapping flows on their floors, such as Tupan, Gish Bar, and Shamshu Paterae. A model by Keszthelyi and others describes how a large sill of magma forms a patera by incorporation of volatile-rich crustal materials into the growing patera, leaving irregular and steep margins [9].

In some cases, the lateral spreading of the magma chamber and subsequent collapse could lead to the formation of an "island" of cold material, such as may have occurred at Loki Patera. Continued magma supply may lead to enlargement of the patera and consumption of the island (Fig. 3).

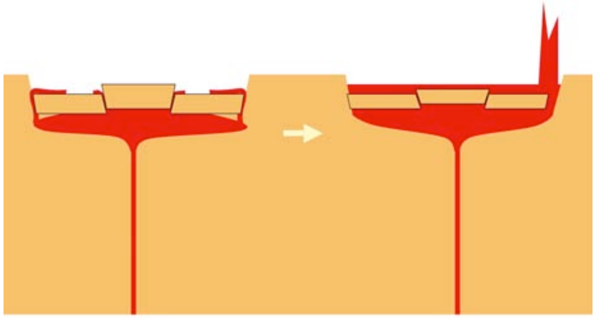

Figure 3. Piecemeal collapse of the patera floor (left) leaves a cold "island" surrounded by lava flows from the margins. This patera could evolve to a filled patera or lava lake (right), or it could continue to evolve laterally, leading to a larger patera with overlapping flows on its floor. Scale of paterae illustrated can range from 15- 200 km in diameter.

VI. Magma supply shuts off to the patera (either permanently or temporarily), it cools down, and becomes covered by plume materials.

Conclusion: This model of patera formation on Io is for a "typical" patera, one that forms alone, in plains, away from mountains. Other models must consider the formation of paterae adjacent to mountains, on shields, and with heavy tectonic influences.

References: [1] Tackley P. J. et al. (2001) *Icarus 149*, 79-93. [2] Tackley P. J. (2001) *JGR 106*, 32,971-32,981. [3] Lopes-Gautier R. et al. (1999) *Icarus 140*, 243-264. [4] Radebaugh et al. (2001) *JGR 106*, 33,005-33,020. [5] O'Reilly T. C. and Davies G. F. (1981) *GRL 8*, 313-316. [6] Davies A. G. et al. (2001) *JGR 106*, 33,079-33,104. [7] Leone G. and Wilson L. (2001) *JGR 106*, 32,983-32,995. [8] Williams D. et al. (2002) *JGR 107*, 5068. doi: 10.1029/2001JE001821. [9] Keszthelyi L. P. et al. (2004) *Icarus 169*, 271-286. [10] Howell R. (1997) *Icarus 127*, 394-407. [11] Radebaugh J. et al. (2004) *Icarus 169*, 65-79.