'ACTIVE' AND 'PASSIVE' LAVA RESURFACING PROCESSES ON IO: A COMPARATIVE STUDY OF LOKI PATERA AND PROMETHEUS. A. G. Davies[1], D. L. Matson[1], G. Leone[2], L. Wilson[2], and L. P. Keszthelyi[3]. [1]Jet Propulsion Laboratory-California Institute of Technology, ms 183-501, 4800 Oak Grove Drive, Pasadena, CA 91109, USA. Tel: 818-393-1775; email: Ashley.Davies@jpl.nasa.gov, Dennis.Matson@jpl.nasa.gov. [2]Lancaster University, Bailrigg, Lancaster, Lancashire, UK, email: gleone@lancs.ac.uk, lwilson@lancs.ac.uk. [3]United States Geological Survey, 2255 Gemini Road, Flagstaff, AZ 86001; email: laz@usgs.gov.

Introduction: Studies of Galileo Near Infrared Mapping Spectrometer (NIMS) data and ground based data of volcanism at Prometheus and Loki Patera on Io [1, 2, 3] reveal very different mechanisms of lava emplacement at these two volcanoes. Data analyses show that the periodic nature of Loki Patera's volcanism from 1990 to 2001 is strong evidence that Loki's resurfacing over this period resulted from the foundering of a crust on a lava lake. This process is designated '*passive*', as there is no reliance on sub-surface processes: the foundering of the crust is inevitable. Prometheus, on the other hand, displays an episodicity in its activity which we designate '*active*'. Like Kilauea, a close analog, Prometheus's effusive volcanism is dominated by pulses of magma through the near-surface plumbing system. Each 'system' affords views of lava resurfacing processes through modelling.

Prometheus: Prometheus has been likened to the 'Old Faithful' geyser because of its prolonged life, and the fact that it's plume was seen to be in eruption in every relevant observation from *Voyager* to *Galileo*. The analogy is more appropriate with the discovery of the episodic nature of Prometheus's volcanism [3], which has been used to constrain magma supply parameters. With an apparent eruptive episode cycle length of ~ 7-9 months, the volume of material erupted per cycle has been estimated to be 0.8 to 3 km^3, at an average eruption rate of 40 to 140 m^3 s^{-1}. Peak rates are almost certainly higher. Magma volume fluxes of 40 to 140 m^3 s^{-1} would imply that the eruptions were fed by turbulent flow through either circular conduits with radii in the range 1 to 2 m or elongate fissure with widths in the range 0.15 to 0.25 m and lengths in the range 80 to 130 m. If the erupting vent were a fissure, its discharge of ~0.5 to 1 m^3 s^{-1} m^{-1} per meter length of fissure would be significantly less than that of the Tvashtar Catena eruption, 6 to 7 m^3 s^{-1} m^{-1} [4].

The presence of magma reservoirs may explain the periodicity, the great extent of the larger lava flow fields, and the longevity of some eruptions. Magma reservoirs act as buffers, accumulating melts supplied from the mantle, and can erupt in a cyclic manner when the surrounding rocks react elastically to overpressuring of the reservoir. In that case, the volume of magma erupted modeled to be about one thousandth of the reservoir volume [5], so the erupted volume of 0.8 to 3 km^3 would imply a reservoir volume of ~1000 to 3000 km^3. Finding room for a reservoir of this size within the crust of Io is not difficult. If a diameter typical of that of Io's calderas, say 40 km, is assumed for the reservoir, its vertical extent would have to be ~2 km. To ensure normal stability of its roof, this would imply that its center would have to be at a depth of ~3 to 5 km. Alternatively, if the reservoir had a more equant shape, its diameter would need to be ~ 5 to 10 km and its center would need to be located at ~5 to 8 km depth.

Prometheus/Kilauea comparison: These reservoir depths and sizes can be compared with those relevant to Kilauea volcano, where the summit reservoir has a vertical extent of ~3 km and is centred at a depth of ~ 3 km. The gravity ratio between Earth and Io is a factor of 5.4, and we expect a proportional ratio in the vertical extents of magma reservoirs [6]. This could imply that on Io possible vertical extents of reservoirs are ~16 km with centers at ~10 km depth. These values are similar to those found above for an equant reservoir on Io. Kilauea has a near-surface summit magma chamber, but the exact geometry is not known (spherical, or dikes and sills). Estimates range from 0.08 to 40 km^3 [7]. Individual eruptive episodes produce volumes typically of less than 0.01 km^3 [8], implying a magma chamber volume of 10 km^3, neatly in the suggested range.

Models of the distribution of crustal density as a function of depth taking account of likely surface deposit porosity and gravitational compaction show that the depth at which rising magma reaches neutral buoyancy, and thus is likely to form a magma reservoir, is critically dependant on magma density. This in turn is dictated by the amounts of dissolved volatiles available to exsolve and form gas bubbles. Calculations based on these principles yield predicted magma reservoir depths for Kilauea that are in agreement with seismic observations. Unfortunately there is much uncertainty about the presence and nature of volatiles in magmas on Io. For example, if we assume a surface void space fraction of ~30%, a surface solid SO_2 volume fraction of ~15%, and a surface solid silicate fraction of ~55%, then a mafic magma with a total juvenile SO_2 contents of 0.15 mass% would reach a neutral buoyancy level at ~30 km depth [9]. Only if the magma contained a larger proportion of SO_2 or some volatile with similar properties would the neutral buoyancy level be as shallow as ~10 km. Furthermore, a significant excess pressure would be needed in the magma reservoir to guarantee that magma was able to erupt to the surface. The lithostatic pressure at 29.6 km depth on Io is ~ 40 MPa [9] and this pressure supports a 3050 kg m^{-3} dense magma column to a vertical height of ~7.3 km. To raise this column the further 2.7 km needed to reach the surface, an excess pressure of ~15 MPa within the reservoir is required. An excess pressure this large is several times higher than that inferred for the reservoirs beneath many terrestrial basaltic volcanoes. It is also likely that reservoir wall failure and dike propagation would have occurred before a pressure this large was reached [10].

There are a number of implications and alternatives to these results. If correct, they suggest that intrusive magmatism should be much more prevalent than volcanism, which has implications for Io's global heat flow and the thermal structure of the lithosphere. Alternatively, the density of the crust could be higher (due to less void space or volatiles), or the magmas may be less dense. Using the mantle composition and degree of partial melting suggested by a recent model for Io's interior [11], the density of the rising magmas may be as low as 2500 kg m^{-3}. Finally, the stress in the Ionian lithosphere is expected to be significantly in excess of lithostatic [12].

Loki Patera: Loki Patera is the most thermally powerful volcano on the Solar System's most volcanic body. The volcanic complex at Loki Patera is a unique feature on Io. Loki has the appearances of a massive lava lake over ~200 km in diameter, and on occasion outputs more than 10^{13} W. Resurfacing at Loki Patera is very different to what is seen at Prometheus, although the proportionally unchanging distribution of thermal emission as a function of wavelength (at least from NIMS data, 0.7 to 5.2 microns) indicates a relatively quiescent process of resurfacing [11]. The behaviour of Loki's thermal emission from 1990 to 2001 was consistent with the foundering of the crust on a lava lake. The temperature, age, and crustal thickness distributions as seen by the *Galileo* NIMS instrument in October 2001 [2] are consistent with the 'foundering crust' model [1]. This foundering process, and the implications for modelling the crustal structure and magma supply and circulatory systems under Loki Patera, are discussed in elsewhere [14].

Loki/Pele/Alae lava lake comparison: If a lava lake, Loki is very different to any other lava lake on Io or Earth. The Pele lava lake is constantly disrupted by exsolving volatiles, something not observed at Loki. Instead, a quiescent emplacement indicates that the magma has a very low gas content, or perhaps the areal extent of the lake allows gas to be released over a broad area. Perhaps the closest terrestrial analog to Loki is the Alae lava lake, Hawai'i, which formed from the 1963 eruption of Kilauea [15] and which solidified after a period of overturning activity.

Conclusions: a comparison of processes: Table 1 summarises the resurfacing processes at Prometheus and Loki Patera. The process at Prometheus is considered 'active' as it results from the interplay of a large number of processes and constraints. Although the episodic magma supply system to Kilauea is not yet fully understood, the episodicity of activity at Prometheus, while strengthening the analogy with the Kilauea, nevertheless allows modelling of the interior structure of the volcano. The resurfacing process at Loki can be denoted as 'passive' as it relies solely on radiative heat and the formation of a crust on the lake. Foundering is inevitable, and yet the simplicity of the process allows detailed constraint of physical parameters and of the magma supply mechanism.

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Table 1

Loki Patera	**Prometheus**
Unique on Io	Common on Io
Passive resurfacing	**Active** resurfacing
Mostly periodic	Episodic behaviour
Resurfacing dominated by foundering of crust	Resurfacing dominated by flows
Possible crust on lava 'sea'? [14]	Kilauea 'magma chamber supply' analog
Mass flux = 15000 m^3/s	Mass flux = 40-140 m^3/s
Flux density: 0.3 kW/m^2	Flux density: 2 kW/m^2
Thermal output (W) = 10^{12}-10^{13}	Thermal output (W) = ~10^{11}

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