AN IMPACT GENESIS FOR LOKI PATERA? I. E. Thorsos[1] and A. G. Davies[2], [1]University of New Mexico Institute of Meteoritics, Department of Earth and Planetary Sciences; e-mail: Thorsos@aol.com, [2]Jet Propulsion Laboratory-California Institute of Technology, ms 183-501, 4800 Oak Grove Drive, Pasadena CA 91109, USA, Tel: 818-393-1775; e-mail: Ashley.Davies@jpl.nasa.gov.

Introduction: What happens when a large impact event takes place on a satellite with a thin crust and lithosphere? In the early Solar System impact cratering and volcanism were the dominate processes shaping the surfaces of the terrestrial planets. Impact events may have triggered additional volcanism by uplifting partially molten mantle material to the surface, where it melts due to pressure release. Subsequently, the shattered crust may have provided pathways for magma to reach the surface creating a longer term hot spot. As the crusts of the terrestrial planets thickened, the ability of impacts to trigger volcanism diminished [1]. However, the highly-volcanic jovian satellite Io is located in a "high-impact" area of the Solar System [2], a victim of material attracted by Jupiter's gravitational field. In 1994 huge impacts were observed when fragments of comet Shoemaker-Levy 9 impacted Jupiter. The large icy satellites of Jupiter (Europa, Ganymede and Callisto) are pock-marked with many impact craters. Yet no impact features have been found on Io [3]. This is because of rapid resurfacing of Io due to volcanism, estimated at ~1 cm/year [4] which over short geological time erases evidence of impacts. Io, however, has a lithosphere over a molten or partially-molten mantle [e.g., 5], and the effects of a sufficiently large impact may extend far beyond the evolution of the impact crater alone. At least one example of impact-triggered volcanism may exist in the Solar System today: the Loki Patera complex on Io.

Loki Patera: The volcanic complex at Loki Patera is a unique feature on Io. Located at approximately 10 N 310 W, Loki Patera is a massive volcanic caldera ("patera") greater than 200 km in diameter. Loki Patera has been described as the most thermally powerful volcano on the Solar System's most volcanic body [6], accounting for roughly 15% of Io's total heat flow [7]. Loki Patera is regularly resurfaced with new lava (either by foundering of the crust on a lava lake or by flows: see summary in [8]). However, this abstract does not address the mechanism of resurfacing, but is concerned with the genesis of this feature, and the need to supply the large volumes of material [e.g., 6] needed to maintain Loki's thermal output. From its appearance (Figure 1), behavior and evolution of thermal output and signature [8,9] Loki Patera appears to be a unique feature on Io. This suggests it may have formed by a different mechanism than the other Ionian volcanoes. We consider an impact-caused genesis for Loki Patera.

Loki Patera Impact Melt Production: We estimate the volume of melt produced from the impact by directly applying scaling relationships developed for the Earth's Moon. The physical characteristics of Io are very similar to the Moon. Io has a diameter of 3630 km, surface gravity of 1.81 m/s and a density of 3.55 g/cm^3 as compared to the Moon's 3476 km, surface gravity of 1.62 m/s, and a density of 3.34 g/cm^3.

The volume of impact melt sheet is calculated using the relationship $V_m = cD_{tc}^d$, where D_{tc} is the transient crater diameter in km, c and d are regression constants [10]. The transient cavity is calculated using the equation $D_c^{0.15} \times D_f^{0.85}$, where D_c is the simple to complex crater transition diameter and D_f is the final crater diameter [11]. The simple to complex transition crater diameter of 18.7 km for the Moon [10] is also applied to Io.

As a conservative estimate for the progenitor of the 200-km-diameter Loki Patera, we use a crater diameter of 175 km. We also make a conservative selection of an impactor as a 10.8 km diameter chondrite asteroid impacting Io at a velocity of only 10 km/s. (A higher velocity comet impact would increase the melt estimate). We apply regression constants c = 0.000108 and d = 3.85 for a chondrite asteroid impacting at a velocity of 10 km/s [10]. For a 175-km crater the volume of impact melt produced is 1.3x10^4 km^3.

Loki Patera: An Example of Impact-Triggered Volcanism? The thin lithosphere (possibly as thin as 10 km, although from considering formation processes for some mountains, no thicker than 80 km in places; see [5] for discussion) on Io may allow the central uplift of the 175-km diameter crater to bring partially molten mantle material to the surface where it will subsequently melt.

To quantify this impact triggered volcanism, the central uplift is modeled as a cylindrical plug to determine its volume and mass. The height of the plug, the stratigraphic uplift (Y_{st}), is found from $Y_{st} = 0.25D_{tc}$ [12]. The approximate width of the central uplift (W_{cu}) is determined from $W_{cu} = 0.22D_f$ [13]. For a 175 km crater on Io, the "cylindrical plug" uplift has an estimated height of 31.6 km and width of 38.5 km, which gives a volume of uplifted material of 3.6x10^4 km^3. Assuming 100% of the uplifted material melts, combining with the melt sheet results in a crater with an initial $5x10^4$ km^3 of melt.

Alternatively, an even more conservative estimation is to apply the "Melosh rule of thumb", where the stratigraphic uplift is approximated as one tenth of the crater diameter [1]. Y_{st} becomes 17.5 km and our "cylindrical plug" morphs into a "hockey puck" uplift. The volume of uplifted material is now $2x10^4$ km^3. When combined with the melt sheet, this more conservative approach results in a total of $3.3x10^4$ km^3 of melt.

The central uplift and deep fracturing due to the crater formation likely provided magma pathways from Io's mantle, forming a hot spot that allowed subsequent eruptions to the surface and perpetuated the volcanic activity.

Implications: The rapid resurfacing of Io combined with an excess of initial melt relative to craters of similar size on the Moon would have obscured the original morphological features of the crater such as the surrounding ejecta blanket, raised crater rim, and terraced walls. The large "island" feature surrounded by low topography flooded with lava slightly in the center in Figure 1 resembles the central uplift and flat floors characteristic of some impact craters seen on Mars.

The creation of Loki by an impact resolves Loki's anomalous features. The large thermal excess would be explained by the impact melt, impact triggered volcanism, and "hot spot" access to the mantle. The "island" can be explained as a central uplift remnant. The uniqueness of Loki can be explained by its genesis due to a large impact, an event, which although rare, probably happened many times during geological time.

If this is the case, then Loki Patera provides a window into impact-triggered volcanism, a key process that likely occurred on the early Earth, before and after the Moon-formation event, and other terrestrial planets when thermal conditions were significantly different than today (i.e. thin crust with higher heat flow) and impact rates were higher.

Acknowledgements: Part of this work was carried out at the Jet Propulsion Laboratory-California Institute of Technology, under contract to NASA. AGD is supported by a grant from the NASA Outer Planets Research Program.

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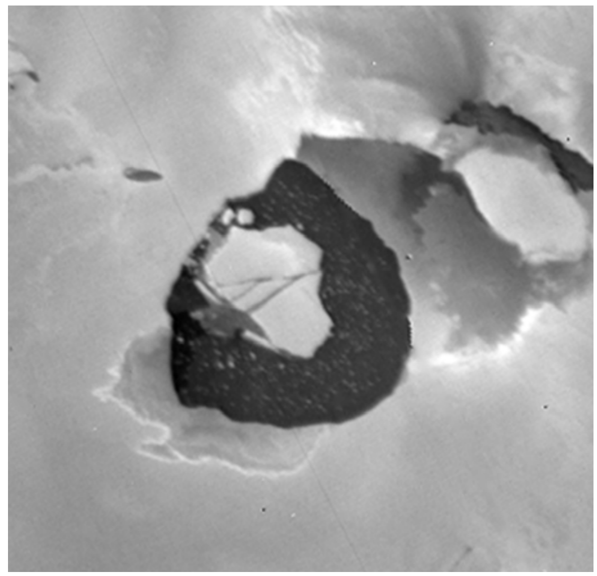

Figure 1: Loki Patera as seen by the *Voyager* spacecraft (detail from NASA image PIA000315). The Loki Patera feature is ~200 km across).