NARROW VERTICAL CAVES: MAPPING VOLCANIC FISSURE GEOMETRIES.

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Introduction: Volcanic conduits are difficult to quantify, but their geometry fundamentally influences how eruptions occur. Increasing our understanding of their size and shape beyond first order simple geometries was proposed as a top priority for the next 100 years of volcanic research by over 200 volcanologist [1]. Here we focus on fissure conduits – elongated narrow cracks in the ground that can occasionally survive the explosive nature of eruptions. Those that do remain intact after the eruption is over give scientists a window into the true magmatic pathway used during eruptions. Since basaltic fissure eruptions are the most common type of volcanic eruption on Earth [2], and also appear to have dominated resurfacing on Moon, Mars, and possibly icy satellites [3], it is highly relevant to document fissure vents and conduits. Our current understanding of terrestrial and planetary eruption mechanisms uses first order geometric assumptions of the conduit shape (i.e., cylindrical pipe or a rectilinear crack (Figure 1)) [4-8], and this assumption directly affects our understanding of eruption dynamics (e.g., magmatic ascent and transport, volcanic jet behavior (including vent modification), and volcanic deposits).

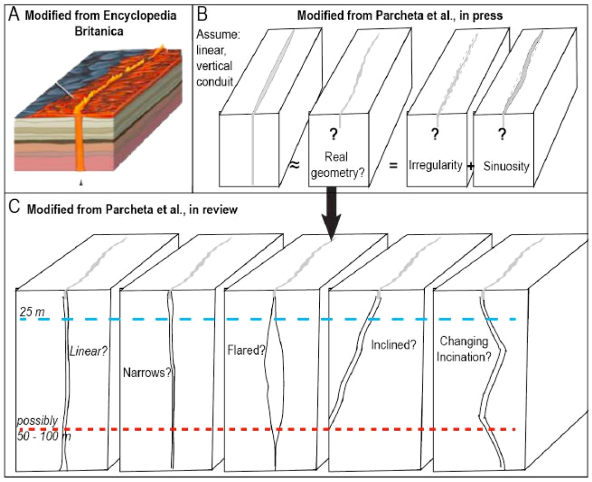

Figure 1 A: modified from [12], depicts the current state of knowledge about fissure conduits: they are linear and vertical. B: modified from Parcheta et al., [in press], depicts a more realistic fissure geometry. C: The blue dashed line in the lower panel indicates the 25 m depth that we have reached with VolcanoBot1. The red line in the lower panel indicates the lower range of depths to which we think the fissure is a subterranean void (50-100 m). Between them are possible geometries that could be present.

Robotic Data Acquisition Approach: Fissures are often too thin to document in detail with seismology or remote geophysical methods. In quantifying a fissure's surface geometry, one must account for non-uniform distribution of wall irregularities, drain back textures, and the larger scale sinuosity of the whole fissure system. Doing this in the third dimension (with depth into the ground) only futher complicates thedocumentation process. To simplify the problem, and collect the first data from an eruptive volcanic fissure, we developed VolcanoBot – a rotary wheeled, near infrared sensing platform to go inside accessible fissures <50 C (Figure 2). The robot's mechanical parts were made "in-house" at the Jet Propulsion Laboratory using 3d printers, milling, casting, and laser cutting techniques [9]. The electronics and instruments were assembled from off-the-shelf components and electronically integrated together. The robot is lowered into vents via thin steel cable tether with communication and power tethers integrated into a cohesive bundle.

Vent And Conduit Geometries: Fissures have three types of variability [10]: cm-scale surface roughness due to lava drain-back, dm-m-scale irregularities due to the fracture mechanics of the host/wall rock, and Dm-hm sinuosities due to the local and regional stress regimes. The drain-back textures represent a 2-7 cm rind on short-lived (<1 day), basaltic fissures, and thus the vent shape is slightly larger (2*rind) than the measured shape [10]. Any flaring in short-lived vents is mechanical in nature [10]. Here we present a comparison of shallow subsurface structures (<30 m depth) with their surface equivalents. We see a self-similar pattern of irregularities on the fissure walls in the subsurface, implying a similar origin to the surface equivalent features. Irregularities are large enough to have affected magmatic transport during fissure eruptions, implying fountains may not be as passive nor as simple as previously thought. Piercing points are present across the fissure walls in some places, but are missing (erosional cavities?) in other places, again implying complex fluid dynamics in the shallow sub-surface during eruption.

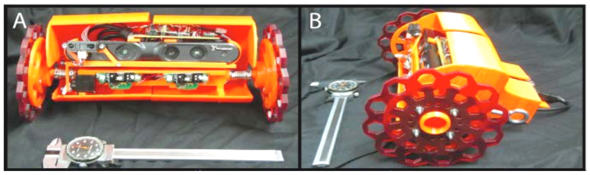

Figure 2 Photos showing VolcanoBot. A, B: Photograph of recently tested VolcanoBot2, a rotary microspine robot, with 12.5 cm diameter wheels and a 25 cm long body.

Planetary and icy satellite volcanism: If fissure vents [7, 11] can be clearly identified in the new high-resolution data from HiRISE and LROC datasets of Mars and Moon, then their surface vent geometry could be mapped to the resolution of the images. From the vent geometry, and the final results of this study, we could potentially infer a general shallow conduit geometry given a known host rock (predetermined irregularity sizes). Should the vents be long enough to record a sinuosity, we would be able to back out knowledge of the local and/or regional stress field that the fissure propagated through, providing insights into the local and or regional crustal environment. Additionally, the south polar cracks of Enceladus are an order of magnitude thinner than basaltic fissures [8,15], but 2-3 orders of magnitude longer [8]. Naturally, their wall "rock" is ice, and we might expect to find irregularities along the vent surface that match the properties of ice fractures due to extension. While further fieldwork is needed to verify crevasse geometries with VolcanoBot, it is anticipated that by knowing the surface irregularities, one would have a better understanding of similar features along the ice conduit walls. This would subsequently allow for a better understanding of cryovolcanic ascent and eruption mechanisms.

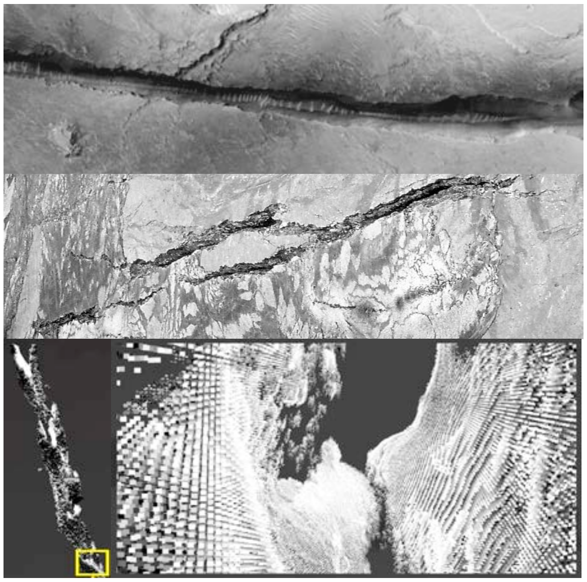

Figure 3 *Top:* Martian fissure from Cerberus Fossae [13]. *Middle:* Aerial Image of the 1971 eruptive fissure at Kilauea's summit [14] *Bottom Left*: Top 5 m of shallow conduit from a Mauna Ulu vent imaged with VolcanoBot. Yellow box denotes image on the right. *Bottom Right*: A look inside a fissure conduit. Two irregularities protrude into the fissure at the same depth – the right side is 0.5 m closer to the camera than the left. White boxes are individual data points.

References: [1] Poland M. et al., (2015) *AGU Monograph 208,* ch 24. [2] MacDonald et al., (1983) *Book: Volcanoes in the Sea.* [3] Lopes et al., (2013) *Book: Modeling Volcanic Processes* [4], Wilson and Head, (1981), *JGR, 86,* 2971-3001. [5] Vernoille and Jaupart (1986), *JVGR, 91,* 1282-1286. [6] Mitchell K.L. (2005), *JVGR*, *143,* 187-203. [7] Wilson et al., (2009) *JVGR 185,* 1:28-46. [8] Goguen et al., (2013), *Icarus, 226,* 1128-1137. [9] Parcheta et al., submitted to Mechatronics, [10] Parcheta et al., (2015) *AGU Monograph 208,* ch 17. [11] Wilson L. and Head J. (1983) Nature, 301, 663-669. [12] Encyclopedia Britannica, "Icelandic Eruption", 2014. [13] http://www.uahirise.org /ESP_018141_1965 [14] http://hvo.wr.usgs.gov/gallery /kilauea/caldera/4303019_L.jpg. [15] Matson et al., (2012), *Icarus, 221,* 53-62.

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