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Pit chains on Enceladus signal the recent tectonic dissection of the ancient cratered terrains

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ABSTRACT

Enceladus is the first outer solar system body on which pit chains have been positively identified. We map the global distribution of pit chains and show that pit chains are among the youngest tectonic features on Enceladus's surface, concentrated in the cratered plains centered on Enceladus's Saturnian and anti-Saturnian hemispheres. Pit chains on Enceladus are interpreted as the surface expressions of subsurface dilational fractures underlying a cover of unconsolidated material, which we infer to be a geologically young cover of loose regolith that mantles the surface of Enceladus. A widespread layer of regolith may act to insulate the surface, which has implications for the thermal state of Enceladus's ice shell. The widespread distribution of pit chains across the cratered plains indicates that this ancient surface has recently been tectonically active.

1. Introduction

Pit chains are collinear assemblages of circular to elliptical depressions (Fig. 1) that are widespread on solid-surface bodies across the solar system. These landforms have been described on Venus (Bleamaster et al., 2004), Earth (Okubo and Martel, 1998; Ferrill et al., 2004, 2011; Wyrick et al., 2004), Mars (Wyrick et al., 2004; Ferrill et al., 2004), and several small solar system bodies, including Phobos (Thomas et al., 1979; Hurford et al., 2016), Eros (Prockter et al., 2002; Buczkowski et al., 2008), Gaspra (Veverka et al., 1994), Ida (Sullivan et al., 1996), and Vesta (Buczkowski et al., 2012a,b,2013; Wyrick et al., 2010) (Fig. 1). Pit chains across the solar system form by a variety of mechanisms, including karst, lava tube collapse, venting processes, extensional fracturing, or dilational faulting (e.g., Wyrick et al., 2004, 2010). Pit chains have also been identified on Enceladus (Michaud et al., 2008); therefore, characterizing the mechanism by which pit chains form on Enceladus will provide insights into the manner in which its icy shell deforms and will further unravel the complex and dynamic geologic history of this moon.

Enceladus's active plume (Porco et al., 2006) and thermal anomaly (Spencer et al., 2006) within the South Polar Terrain (SPT) make Enceladus one of the few geologically active bodies in the solar system and a primary astrobiological target. These SPT jets act as a source of fall-back material that may have mantled Enceladus's surface (Porco et al., 2006; Kempf et al., 2010) and, in part, contributed to the muted morphologies of craters (Bray et al., 2007; Kirchoff and Schenk, 2009; Bland et al., 2012) and tectonic landforms observed across Enceladus (Crow-Willard and Pappalardo, 2015). Therefore, any recent tectonic dissection of the surface would necessarily have interacted with this mantled surface. Pit chains were initially reported within the ancient cratered plains (Fig. 2) centered near the Saturnian (0°) and anti-Saturnian (180°) points (Michaud et al., 2008). Here, we aim to characterize pit chains on Enceladus and determine their likely formation mechanism(s) by assessing their spatial distribution, their age relative to other terrains, and their relationship or interaction with the recently mantled surface.

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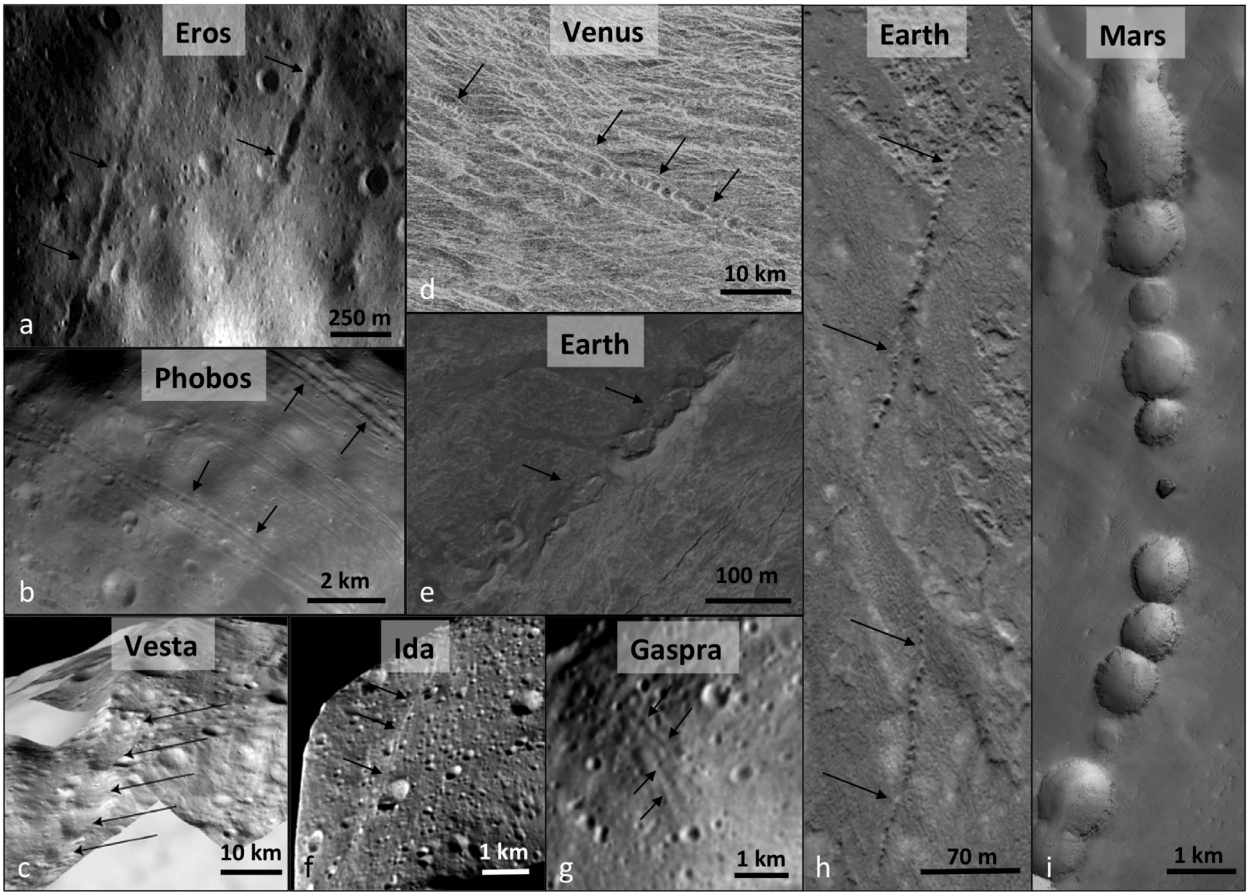

Fig. 1. The morphology of pit chains across the solar system. **a.** Eros from *NEAR*. Image no. 135344864 (Buczkowski et al., 2008). **b.** Phobos. Image PIA10367. **c.** Albalonga Catena, Vesta. Modified after Buczkowski et al. (2013). **d.** Venus. Right-look Magellan data near 13°S, 112°E (Bleamaster et al., 2004). **e.** Kilauea Volcano, Hawaii centered at 19.3909°N 155.3076°W. Image taken 12/06/2014, acquired from Google Earth on 04/20/2016. **f.** Ida, modified from image PIA00332. **g.** Gaspra, modified from Galileo image PIA00332. **h.** Pit chains in northeastern Iceland centered near 65.9902°N and 16.5301°W (see also Figs. 3a & 5 in Ferrill et al., 2011). Image taken on 7/27/2012, acquired from Google Earth 04/20/2016. **i.** Pit chains on Mars from the Mars Global Surveyor Mars Orbiter Camera, centered near 6.5398°S and 119.9703°W on the flank of Arsia Mons. Image PIA02874.

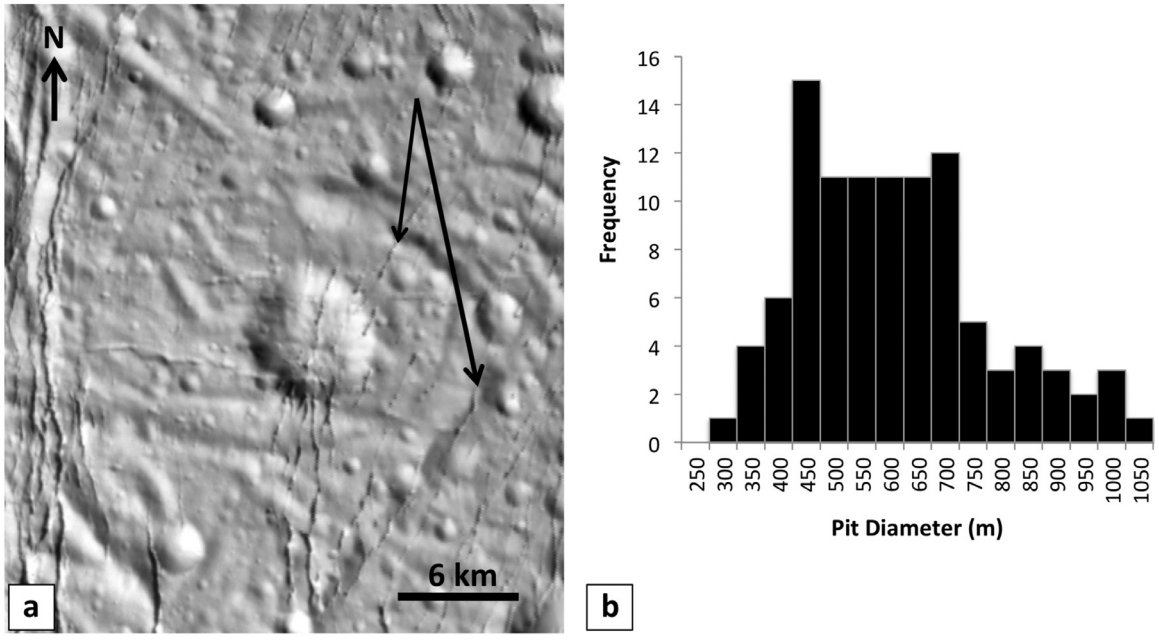

Fig. 2. **a.** Pit chains on Enceladus are composed of collinear, isolated pits. Cassini ISS Image No. N1489050144 centered at 4°E, 152°N with a resolution of 75 m/pixel. **b.** A histogram of pit chain diameters showing a range of 300–1000 m. The population represented in this histogram are from a sampling of pits across the surface.

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