IMAGING THE SUBSURFACE STRUCTURE OF PIT CRATERS. Craig Magee[1], Chris Jackson[2], Corbin L. Kling[3,4], and Paul K. Byrne[4], [1]Institute of Geophysics and Tectonics, School of Earth Science and Environment, University of Leeds, Leeds, LS2 9JT, UK (c.magee@leeds.ac.uk) for first author, [2]Department of Earth and Environmental Sciences, The University of Manchester, Williamson Building, Oxford Road, Manchester, M13 9PL, UK, [3]Center for Earth and Planetary Studies, Smithsonian Institution, Washington, DC 20560, [4]Planetary Research Group, Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, NC 27695, USA.

Introduction: Pit craters are enigmatic, sub-circular depressions observed on rocky and icy planetary bodies across the Solar System (e.g., **Fig. 1**). These craters do not primarily form *during* catastrophic impact or the forcible eruption of subsurface materials, but likely due to collapse of subsurface cavities *following* fluid (e.g., magma) movement and/or extensional tectonics. Pit craters thus provide important surficial records of otherwise inaccessible subsurface processes. However, unlocking these pit crater archives is difficult because we do not know how their surface expression relates to their subsurface structure or driving mechanisms [1]. As such, there is a variety of hypotheses concerning pit crater formation, which variously relate cavity collapse to: (i) opening of dilatational jogs during faulting; (ii) tensile fracturing; (iii) karst development; (iv) permafrost melting; (v) lava tube evacuation; (vi) volatile release from dyke tip process zones; (vii) pressure waning behind a propagating dike tip; (viii) migration of magma away from a reservoir; and/or (ix) hydrothermal fluid movement inducing host rock porosity collapse. Validating whether these proposed mechanisms can drive pit crater formation and, if so, identifying how the physical characteristics of pits can be used to infer their driving mechanisms, is critical to probing subsurface processes on Earth and other planetary bodies.

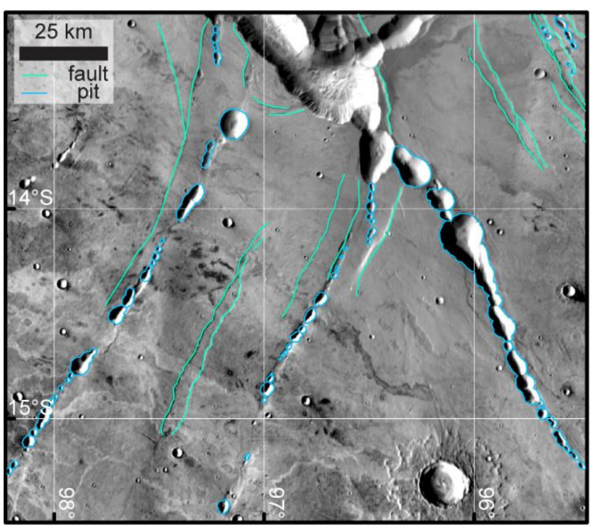

Figure 1: Pit craters and normal faults located on the southeast margin of Noctis Labyrinthus, Mars. Pits tend to form chains and increase in size to the north.

Here we use seismic reflection data from the North Carnarvon Basin offshore NW Australia, which provides ultrasound-like images of Earth's subsurface, to characterize the 3D subsurface structure of natural pit craters (e.g., **Fig. 2**). We extracted geometric data for 61 pits, and find that they are broadly cylindrical, with some displaying an inverted conical (trumpet-like) morphology at their tops (**Fig. 2**). The rims of the pit craters, as well as the upper tips of spatially and potentially genetically related, dike-induced normal faults, occur at or just below the base Cretaceous unconformity and are filled by overlying strata (**Fig 2**). We interpret these seismic–stratigraphic relationships to indicate that these pit craters developed in the latest Jurassic and have since been buried. It is difficult to establish whether seismic reflections within the upper, inverted conical portions of the pit craters represent subsided material or post-emplacement sediment infill. Defining the crater depth, i.e. the height of the depression expressed at the contemporaneous surface immediately after its formation, is thus challenging. We therefore assume crater depth corresponds to the distance between the top of the pit crater and, if present, the transition from an inverted conical morphology to a cylindrical pipe.

Fifty-six pit craters, which are sub-circular and have widths of ~150–740 m, extend down ~500 m to and are aligned in chains above the upper tips of dikes (e.g., **Fig. 2**); crater depths are ~12–225 m. These dike-related pit craters occur within long, linear graben interpreted to be bound by dyke-induced normal faults (**Fig. 2**). Five pit craters, which are ~140–740 m wide and ~32–107 m deep, formed independent of dykes and are associated only with tectonic normal faults; these seismic data thus allow us to compare the physical characteristics of pits generated by diking with those formed by purely tectonic processes. Our preliminary data reveal a moderate, positive correlation between crater width and depth; there is no distinction between the depth and width trends of pit craters associated with dikes and those with tectonic normal faults.

To test whether our quantitative data can be used to inform interpretation of pit craters observed on other planetary bodies, we compare their morphology to those imaged in Noctis Labyrinthus on Mars. Noctis

Labyrinthus, located east of the Tharsis Rise and west of Valles Marineris, is a structurally complex region of Mars, dominated by normal faults, periglacial signatures, landslides, normal faults, and pit craters (e.g., **Fig. 1**) [2-4]. There are >200 pit craters in Noctis Labyrinthus, most of which occur in chains. Pits range in width from 369–11743 m and have depths of 1–1858 m; i.e. they are often much larger than pits observed on Earth. These Martian pit craters all have an inverted conical shape, partly infilled with fine-grained regolith material (though degree of infilling is not discernable). Resistant layers are visible in the upper walls of the pits, indicative of a mechanically variable host stratigraphy. We do not find substantial evidence of pit formation due to diking within Noctis Labyrinthus, although we acknowledge such evidence could be masked by secondary mass wasting processes.

Overall, we show reflection seismology is a powerful tool for studying the three-dimensional geometry of pit craters, with which we can test pit crater formation mechanisms. We anticipate future seismic-based studies will improve our understanding of how the surface expressions of pit craters (either in subaerial or submarine settings) can be used to reconstruct subsurface structures and processes on other planetary bodies, where such subsurface information is not currently available.

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References: [1] Wyrick, D. et al., (2004) *JGR: Planets*, 109(E6); [2] Leone, G. (2014) *JVGR*, 277, 1-8; [3] Rodriguez, J. et al., (2016) *PSS*, 124, 1-14; [4] Andrews-Hannah, J., (2012) *JGR: Planets*, 117(6).

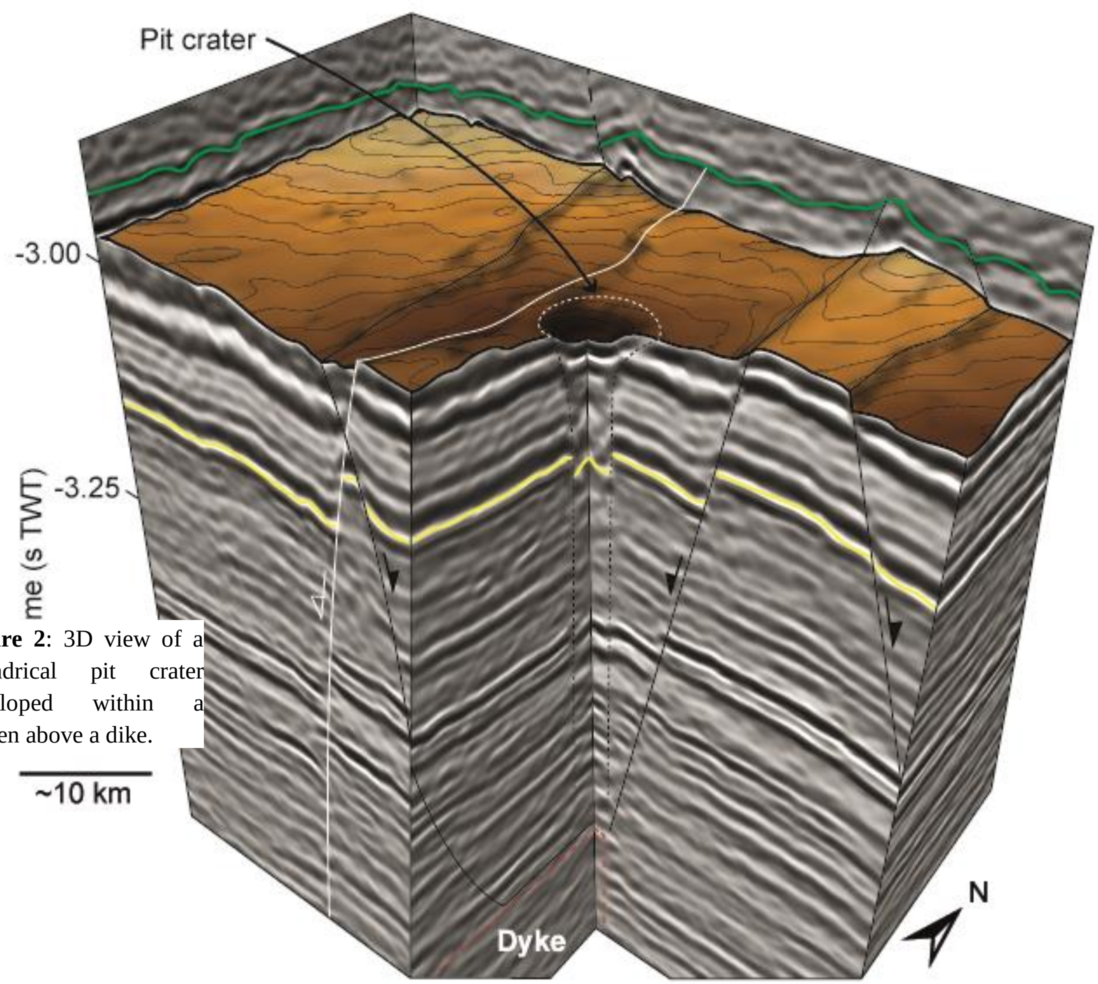

Figure 2: 3D view of a cylindrical pit crater developed within a graben above a dike.