Probabilistic Limit Analysis for Collapse Reconstruction and Stability Assessment of Lunar Lava Tubes (PROMISE)

Extraterrestrial lava tubes: our future home?

Lava tubes (aka pyroducts) are volcanic features with tunnel-like architecture which are formed when the supply of lava stops, lava is drained downslope and leaves partially empty conduits. An important aspects of lava tubes is the tendency for the roof rock to collapse, producing collapse pits (or skylights). These skylights help identify the presence of lava tubes, but pose a threat as they reveal the unstable nature of these structures (see Fig. 1). Lava tubes are common on Earth and they have been identified on the Moon and Mars, where they are likely widespread. Of particular importance is the opportunity they offer us – the potential large sizes and tunnel-like architecture of lava tubes would make them ideal shelters against surface hazards (such as extreme temperature variations, radiation, and micrometeoroids) during planetary missions. From this perspective lunar lava tubes have great promise for the future human exploration of objects beyond Earth. Just as our ancient ancestors used caves as shelters, we now face the exciting possibility of using analogous natural environments on the Moon. In addition to being a shelter for humans, lava tubes offer enormous potential for scientific research in geology, solar system body formation, astrobiology, and are a great place to carry out mining operations. And naturally, it follows that the planning of any human activity in lunar lava tubes will require extension of our knowledge on collapse processes, investigation of their stability and safety, which is a goal central this project. Yet, the project focuses on reliable reconstruction of intact parts of lunar lava tubes by using an innovative computational approach.

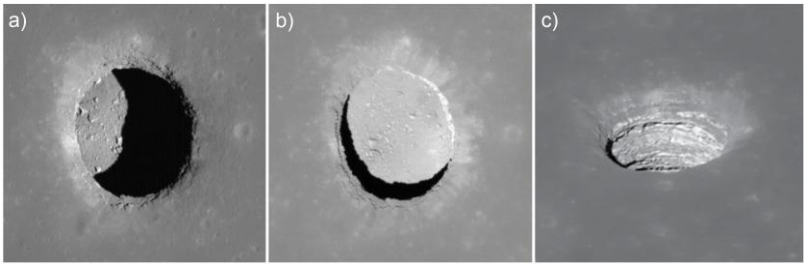

Fig. 1. Lava tube collapse example of Mare Tranquillitatis pit on the Moon captured from different angles by Lunar Reconnaissance Orbiter Camera.

PROMISE in a nutshell

The fact that a specific collapse geometry exists carries a substantial information that has not been used so far in relation to the estimation of lunar lava tube shapes, sizes, and stability. As collapse occurs in the weakest areas of a lava tube roof rocks (e.g., at its thinness point; at the weakest rock strength parameters; or where fractures are present), the project aims to reveal these characteristics by using backward analysis of collapse geometry obtained from numerical approach. PROMISE will search for the optimal lava tube geometry reconstruction (the one for which sufficiently similar collapse geometry is obtained in comparison with the one identified based on spacecraft observations). In other words, in the challenge formulated in this way, for example, the unknown geometry of the lava tube will be sought, which will allow to obtain similar collapses to the one already observed. The project will improve our understanding of lava tube collapse structure, their shapes, sizes, and provide robust constraints on collapse hazards at lava tubes on the Moon. The natural likelihood of using extraterrestrial lava tubes as shelters during planetary missions on the Moon, and farther, makes PROMISE the promise of a new frontier in space exploration and safe future human activity in solar system. The innovative nature of the project and the cross-discipline approach will bring important breakthroughs into planetary geology and geotechnical engineering and will initiate a new branch of research aimed at extracting new information and knowledge from the wide spectrum of collapse structures observed on the surfaces of rocky planetary bodies in our solar system. The method created will be an invaluable tool for researchers who will study lava tubes as more planetary images become available (e.g., in the upcoming NASA mission to Venus, VERITAS, or planned mission to explore lunar collapse interiors).