Evidence for an Explosive Origin of Central Pit Craters on Mars

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Kilometer-scale pit craters are nested in the centers of many impact craters on Mars as well as on icy satellites. They have been inferred to form in the presence of a water-ice rich substrate; however, the process(es) responsible for their formation is still debated. Leading hypotheses invoke origins by either explosive excavation, or by subsurface drainage and collapse. If explosive excavation forms central pit craters, ejecta blankets should be draped around the pits, whereas internal collapse should not deposit significant material outside pit rims. We examined the morphology and thermophysical characteristics of central pits for evidence of ejecta blankets.

Using visible wavelength images from the MRO CTX and HiRISE instruments and thermal infrared images from the Odyssey THEMIS instrument, we conducted a survey to characterize in detail the global population of central pits in impact craters ≥10 km in diameter. We observed raised rims around many central pits, with morphologies similar to rims around impact craters and maar volcanoes. Our analysis of thermal images suggests that blocky materials – which we interpret as pit ejecta – are draped around many central pits on the floors of their parent craters. These findings support an explosive origin for central pit craters on Mars.

Although a few central pit craters have been found on Mercury and the Moon, the preponderance of central pits on icy or ice-rich planetary bodies suggests that water greatly enhances central pit formation. On Earth, hectometer to kilometer-scale craters can form during monogenetic maar volcano eruptions where magma comes into contact with groundwater or ice. Despite small volumes of erupted magma, these phreatomagmatic steam explosions can produce large craters. The largest known maar volcanoes on Earth occur on the Seward Peninsula in northwest Alaska and are up to 8 km in diameter – comparable in size to central pits on Mars. The relatively larger size of the Seward Peninsula maars compared to other terrestrial maars is thought to be due to the interaction of magma with permafrost, as opposed to liquid groundwater. Explosivity for fuel-coolant reactions may be optimized in permafrost due to optimal water/melt mass ratios and the buffering effect of having to melt the ice first. Central pits on Mars would not require endogenic martian sources of heat and volcanism, since more than enough impact melt would already be present from the parent impact event. We calculated the available thermal energy for example central pit craters using relations between crater diameter, energy, and estimates of the mass of impact melt. Our calculations show that, if the upper ~kilometer of the surface had several percent permafrost ice, then the impact melt from the parent impacts have more than enough thermal energy to drive steam explosions capable of producing kilometer-sized central pits on Mars.