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Mercury's Crater-Hosted Hollows: Chalcogenide Pryo-Thermokarst, and Permafrost Analogs on Earth, Mars, and Titan

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MESSENGER has acquired stunning images of pitted, light-toned and variegated light/dark terrains located primarily on the floors—probably impact-melt sheets—of many of Mercury's large craters. Termed "hollows", the pitted terrains are geomorphologically similar to some on Mars formed by sublimation of ice-rich permafrost and to lowland thermokarst on Earth formed by permafrost thaw; to "swiss cheese" terrain forming by sublimation of frozen CO_2 at the Martian South Pole; and to suspected hydrocarbon thermokarst at Titan's poles. I shall briefly review some analogs on these other worlds.

The most plausible explanation for Mercury's hollows is terrain degradation involving melting or sublimation of heterogeneous chalcogenide and sulfosalt mineral assemblages. I refer to these Mercurian features as pyrothermokarst; the etymological redundancy distinguishes the conditions and mineral agents from the ice-related features on Earth and Mars, though some of the physical processes may be similar. Whereas ice and sulfur have long been suspected and ice recently was discovered in permanently shadowed craters of Mercury's polar regions, the hollows occur down to the equator, where neither ice nor sulfur is plausible. The responsible volatiles must be only slightly volatile on the surface and/or in the upper crust of Mercury's low to middle latitudes at 400-800 K, but they must be capable of either melting or sublimating on geologically long time scales. Under prevailing upper crustal and surface temperatures, chalcophile-rich "permafrost" can undergo either desulfidation or melting reactions that could cause migration or volume changes of the permafrost, and hence lead to collapse and pitting.

I propose the initial emplacement of crater-hosted chalcogenides, sulfosalts and related chalcophile materials such as pnictides, in impact-melt pools (involving solid-liquid and silicate-sulfide fractionation) and further differentiation by associated dry or humid fumaroles (solid-vapor and liquid-vapor fractionation and recondensation). Key phase transitions can occur in the temperature range of Mercury's surface and upper crust. Vapor-solid, vapor-liquid, and solid-liquid transitions of the heated materials resulted in migration and loss of volatiles and anatectic liquids, causing collapse pits to form. Seasonal heating near perihelion may work together with geothermal flux or early impact heating to drive off volatiles and produce the pits.

In some cases, local recondensation of moderately volatile materials may have occurred on the rims of the pits; some volatiles may have been transported to the polar regions or lost by exospheric escape. Impacts by comets may have caused local oxidation and formation of oxygenated salts and other minerals, whose local recondensation from fumarole gases can explain the light-toned layers and light-toned rims of many pits. Plating of native volatile metals and semi-metals may also account for some light-toned deposits. Large contrasts in thermal conductivity as well as local topographic shading and latitude controls may result in large differences in element mobility and mineral assemblages. Pyrothermokarst on Mercury may be more chemically heterogeneous and complex in its development than any other thermokarst in the Solar System. Validation of this model would require a future mission with high-resolution multispectral imaging and neutral/ion detection.