

Could Solar Wind Have Decreased Permeability on Mercury and Other Airless Worlds?

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The discovery of a kilometer-scale (km-scale) Volatile-Rich Layer (VRL) within Mercury's upper crust challenges longstanding models that predict volatile depletion due to the planet's proximity to the Sun. Chaotic terrains indicate that this VRL emerges near the surface in some regions, whereas elsewhere it remains buried beneath lava flows and ejecta. In buried locations, impacts locally expose the VRL, producing lobate, glacier-like morphologies. The VRL appears to be ancient, likely forming before the Late Heavy Bombardment (~4 Ga). Progressive solar insolation may have destabilized portions of this layer, whereas episodic volcanic activity may have introduced additional volatile phases. However, the mechanisms that preserve metastable outcrops at or near the surface remain poorly understood. Although Mercury possesses a global magnetic field, it is comparatively weak, and its magnetosphere does not fully shield the planet from the solar wind. Consequently, solar wind ions regularly breach Mercury's magnetosphere and impact the surface. This high flux of charged particles, enhanced by the planet's close proximity to the Sun, likely increases electrostatic charging in Mercury's near-surface environment. Elevated electrostatic forces can promote particle adhesion or partial sintering, which reduce local permeability. Mathematically, this phenomenon is described by Coulomb forces, which on Mercury can exceed grain weight and induce grain aggregation. According to the Kozeny–Carman relationship, even modest decreases in porosity dramatically reduce permeability, effectively stabilizing volatiles by limiting fluid migration. These processes imply that direct solar wind interactions on Mercury's surface contributed to preserving near-surface volatiles despite the presence of a magnetosphere. They also suggest that similar electrostatic charging and resultant permeability reductions may influence volatile retention on the Moon, as well as on exoplanets subjected to intense stellar wind fluxes.

Keywords: Mercury, Regolith, Solar wind, Permeability