Manganese (Hydr)Oxides Record the Dynamic Evolution of a Million-Year Hesperian Ocean in Utopia Planitia, Mars

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ABSTRACT

The evolutionary and duration history of ancient surface water on Mars remains one of the most significant challenges in unraveling the planet's past habitability. Utopia Planitia, a vast basin in Mars' northern lowlands, serves as a critical region for deciphering the past aqueous activity. Here, we present the quantitative evidence of dynamic aqueous evolution and the persistence history of the Hesperian Ocean in Utopia Planitia. By developing a novel deep learning Spectral Contrastive-Aware Network (SCANet), we conduct quantitative analyses of Mn (hydr)oxides in the short-wave infrared (SWIR) spectra from the Zhurong rover and OMEGA spectrometer. Our findings reveal a distinctive altitude-dependent "bathtub ring" pattern of Mn (hydr)oxides, strongly supporting the presence of a large ancient water body. By mapping the spatiotemporal distribution of Mn (hydr)oxides, we reconstruct the evolution of the ancient Hesperian Ocean, detailing its origin, flourishing, regression, and eventual extinction. Quantitative modelling of Mn (hydr)oxides deposition rates further constrains the ocean's duration, providing refined temporal estimates for the persistence of Martian water bodies. These results enhance our understanding of Mars' aqueous evolution, with implications for its past and future habitability.