Thermal and Morphological Analysis of Lunar Lava Flows Using Machine Learning and Stefan-Boltzmann Modeling

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The objective of this research was to develop a dual-methodology framework for the autonomous identification and physical characterization of lunar lava flows using multi-modal orbital data. While current NASA initiatives emphasize human-led "citizen science," this project proposes a scalable computational alternative. A Convolutional Neural Network (CNN) was engineered to classify lunar morphology using high-resolution imagery from the Lunar Reconnaissance Orbiter Camera (LROC). A dataset of 1,000 tiles was curated from three distinct volcanic regions: Hadley Rille, Archimedes Crater, and Mare Serenitatis. The model utilized a 70/15/15 split for training, validation, and testing. To transition from visual classification to physical analysis, topographic profiles were extracted from the Lunar Orbiter Laser Altimeter (LOLA) to determine flow thickness via elevation differential analysis. These measurements were integrated into a physics-based thermal model utilizing the Stefan-Boltzmann Law to simulate radiative cooling durations under lunar environmental constraints. The CNN achieved a classification accuracy of 94.2% (Precision of 0.91, Recall of 0.86, F1-score of 0.88), demonstrating high reliability in distinguishing basaltic flows from complex background terrain. Thermal modeling revealed a strong linear positive correlation between flow thickness and radiative cooling duration, providing a quantitative method for estimating the heat-transfer history of identified flows. This integrated approach demonstrates that combining deep learning with thermophysical constraints significantly enhances the utility of automated planetary mapping, offering a scalable, robust tool for Artemis landing site selection and the geological characterization of the lunar surface.

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