



Multi-wavelength Polarimetric Radar Analysis of Lava Flows at Askja, Iceland: A Venus Analogue Study

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Venus' dense atmosphere prevents optical surface observation, making radar the only geological analysis method. Without ground truth on Venus, terrestrial analogues provide the only means to validate radar interpretation techniques.

Venus' surface is dominated by volcanic terrain [2] and understanding what changes the new missions may 'see' requires analysis of radar signatures at barren, volcanic terrains on Earth. The Askja volcanic area provides an ideal natural laboratory [1] basaltic composition, diverse flows (historical to >6100 years), minimal vegetation cover, and accessibility for validation [5,6]. Key questions include: (1) Can we differentiate volcanic surfaces using radar backscatter? (2) Can we date flows based on radar characteristics? (3) Can we identify flow emplacement and modification processes?

Methodology and Data Acquisition

This research analyses ten lava flow units from the 1961 Vikrahraun eruption to >6100-year-old flows using multi-scale radar data: high-resolution F-SAR (2m), which was collected by the DLR for the VERITAS mission in Aug 2023, at X-band (3.1 cm), S-band (9.4 cm), and L-band (23.8 cm) with full polarimetry [3,4], and Sentinel-1 C-band (30m) [7]. Flow units are mapped using radar imagery, stratigraphic relationships, and field data.

Key Findings

Backscatter curves as a function of incidence angle for individual lava flows show a strong decrease in backscatter with increasing incidence angle (10-15 dB decrease from 10° to 80°), consistent with typical radar scattering behaviour from rough surfaces.

S-band HH analysis reveals systematic changes in backscatter with increasing age: youngest flows (1961) show highest mean backscatter (-7.9 dB), and the oldest flows (>6100 years) show lowest

(-16.8 dB); ca 10 dB backscatter decrease over 6000 years. This marked decrease with flow age is caused by post-emplacement weathering, smoothing and mantling.

The age-backscatter correlations across X, C, S, and L bands reflect systematic changes in lava flow surface characteristics over time. Young flows with original emplacement textures produce high backscatter, while older flows develop smoother surfaces through weathering, resulting in lower backscatter. Surface roughness and backscatter decrease with age, enabling relative dating using multi-parameter radar data.

Wavelength comparison reveals progressive decrease in contrast and dynamic range from L-band through S-band to X-band, with enhanced discrimination at longer wavelengths. L-band with cross-polarized (HV) channel provides the highest dynamic range, optimal for flow differentiation.

Polarimetric analysis successfully differentiates surface scattering mechanisms and flow morphologies. High HH and HH/HV ratios indicate smooth pāhoehoe flows and mantled surfaces, while high HV backscatter indicates rough a'ā flows and steep terrain slopes. Decomposition analysis further enhances morphological discrimination capabilities.

Implications and Conclusions

This study demonstrates that multi-parameter radar data enables discrimination of flow morphologies and ages through wavelength-scale roughness analysis. Age-backscatter correlations provide quantitative dating frameworks, while polarimetric analysis enables morphological and textural discrimination. These findings provide ground truth for interpreting radar signatures of volcanic terrains on Venus, supporting upcoming VERITAS and EnVision missions.

References: [1] Adeli et al., 2023; [2] Brossier et al., 2020; [3] Horn et al., 2017; [4] Keller et al., 2024; [5] Mason et al., 2024; [6] Raguso et al., 2025; [7] Torres et al., 2012.