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Vesicular lavas on Venus: Effects on radar echo and radio brightness temperature

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Abstract

Integrated study of radar dark lava flow in Bereghinia Planitia revealed flow apparent temperature excess up to 90 K suggesting a very recent flow emplacement. Vesicular lava with 0.4 – 5 mm bubbles can explain variations of observed radar echo and variations of derived temperature excess.

1. Introduction

Structure of the upper surface interface and attenuation of microwave radiation inside the surface affect the chance to observe subsurface. Earth-based polarimetric observations showed that some lava flows on Venus return radar echo with significant linearly polarized component, when illuminated by circularly polarized signal [1]. This can occur only when target surfaces are very smooth and rather transparent for radio waves, so the waves scattered at internal interfaces or inclusions can reach the observer.

The present work analyzes an effect of lava volume scattering due to gas vesicles on observed flow thermal emission and radar brightness. Magellan data (λ = 12.6 cm) were used in this study.

2. Flow temperature excess

The flow under study is located at about 28°E, 39°N in Bereghinia Planitia. The flow (Fig. 1a) is radar dark as seen in Magellan SAR image (at incidence angle θ of ~39°), and in Earth-based observations at θ = ~60 [1]. Thus the flow is expected to be smooth at spatial scales < 12.6 cm, which control oblique backscattering.

The flow is also very smooth (roughness is ~0.4°) at larger spatial scales as seen in roughness map shown in Fig. 1b. Earth-based radar polarimetric observations [1] showed that this flow exhibits up to 12% level of linear polarization.

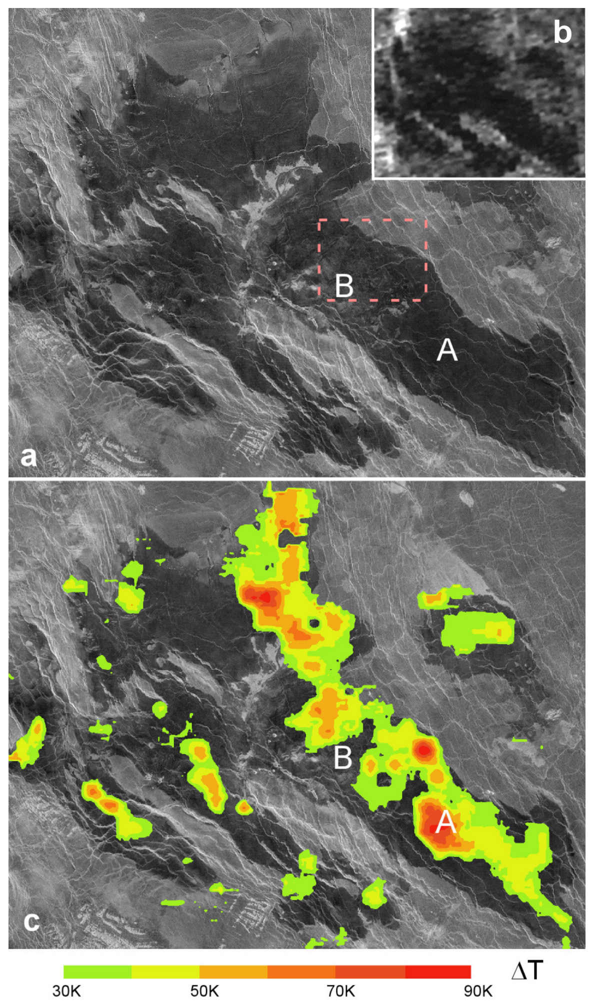

Figure 1: Lava flow in Bereghinia Planitia: a) SAR image; b) roughness map; c) temperature excess.

The apparent surface temperature has been calculated [2] from the observed radio brightness temperature assuming smooth interface with dielectric permittivity ε derived through the "Fresnel reflectivity" obtained in Magellan radar altimetry experiment. If lava flow has a smooth upper interface, a positive excess of the apparent temperature ΔT over the physical temperature of the surface can be due to increased temperature in the shallow subsurface.

Calculated ΔT of the flow is presented in Fig. 1c. It varies from equilibrium state (no thermal excess) up to ~90 K. The highest ΔT seems to be associated with the darkest flow parts (site *A* in Fig. 1c). Low (or no) thermal excess is usually seen in the boundary areas possibly characterized by lower flow thickness. For thicker lavas the thermal effect may last significantly longer.

3. Vesicular lava

Both observed radar cross-section σ and apparent brightness temperature depend on attenuation of radiation in the flow. An attenuation of radiation is proportional to $\exp(-\tau(\kappa_e,z))$. $\tau(\kappa_e,z)$ is optical thickness of the flow down to depth z. For homogeneous material, $\tau = \kappa_e \cdot z$. κ_e is extinction coefficient. $\kappa_e = \kappa_a + \kappa_s$, where κ_a and κ_s are absorption and volume scattering coefficients, respectively. Optical thickness is two times higher for active radar probing in comparison with passive radiometry given the same depth of the flow under study.

With uniform temperature profile and smooth upper flow interface, 80% of the whole thermal emission is formed in the upper layer from the surface down to $\tau = 1.7$, 90% – to $\tau \approx 2.4$, and 100% – to $\tau \approx 10$. If the flow material $\varepsilon = 6.48$ (site *A*, Fig. 1) and loss factor $\tan\delta = 0.004$, 10% of the whole thermal emission is formed at depths of 5–21 m. This estimate shows that noticeable part of thermal emission probes deep subsurface. The thickness of the flow in many sites appear to be at least ~100 m to allow flooded wrinkle ridges shown in Fig. 2 (marked with arrows).

When flow has smooth upper interface and is 100 m thick, radiation has no chance to reach the flow bottom and radar echo has to be formed inside the flow body. Gas vesicles seem to be candidates for scatterers. Vesicular rocks are known on Earth, Mars and Moon and are hypothesized on Venus [3]. Flow porosity n of 10% and bubbles radius r of 0.4 mm provide $\kappa_e = 0.0048$ cm^{-1} and fit observed σ in site *A*, Fig. 1. Material in site *B* (Fig. 1) needs n=32% to explain $\varepsilon \approx 4$. Higher n means higher volatile content and larger bubbles [3]. If r=4.5 mm, κ_e=0.01 cm^{-1} which twice decreases flow depths accessible for the sensing.

On Earth bubbles in rocks reach ~5 mm in size and can form gas blisters (~50 cm) in the middle of the flow [4]. On Venus bubbles are expected to be larger in sizes than on Earth [3]. Thinner flow over the wrinkle ridge (site A, Fig. 2) can explain lower σ in comparison with σ in site B (Fig. 2) where thicker flow is expected.

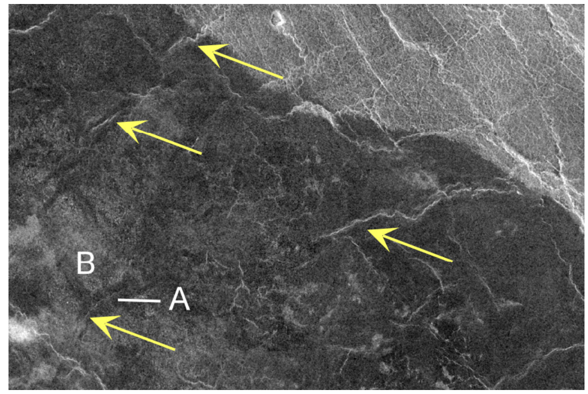

Figure 2: Flooded wrinkle ridges.

6. Conclusions

Vesicular lavas can explain variations of both radar brightness and temperature excess over the flow area. Lava emplacement in the site of the study seems to go with variations in volatile content in the range of 0.2 – 0.6% of CO_2.

References

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