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THE UNIQUE RADAR SCATTERING PROPERTIES OF SILICIC LAVA FLOWS AND DOMES

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1. INTRODUCTION

Silicic (silica-rich) lava flows, such as rhyolite, rhyodacite, and dacite, possess unique physical properties primarily because of the relatively high viscosity of the molten lava. Silicic flows tend to be thicker than basaltic flows, and the resulting large-scale morphology is typically a steep-sided dome or flow lobe, with aspect ratios (height/length) sometimes approaching unity. The upper surfaces of silicic domes and flows are normally emplaced as relatively cool, brittle slabs that fracture as they are extruded from the central vent areas, and are then rafted away toward the flow margin as a brittle carapace above a more ductile interior layer. This mode of emplacement results in a surface with unique roughness characteristics, which can be well-characterized by multi-parameter synthetic aperture radar (SAR) observations. In this paper, we examine the scattering properties of several silicic domes in the Inyo volcanic chain in the Eastern Sierra of California, using AIRSAR and TOPSAR data. Field measurements of intermediate-scale (cm to tens of m) surface topography and block size are used to assess the mechanisms of the scattering process, and to quantify the unique roughness characteristics of the flow surfaces.

2. GEOLOGIC SETTING

The Inyo volcanic chain represents the most recent eruptive activity (500-1200 years before present) in the Long Valley Caldera volcanic complex [Miller, 1985]. Deadman, Glass Creek, Obsidian, and Wilson Butte domes form a north-south trending chain of rhyolite flows, each 0.8 to 1.8 km in diameter, along the northwestern edge of the Long Valley Caldera. The lava textures include coarsely and finely vesicular pumice (CVP and FVP) and dense massive obsidian. CVP and obsidian are often associated with upwelling zones and "crease structures" [Anderson and Fink, 1992], while FVP is the dominant texture on most of the dome carapace. We have identified four distinct morphological units on the Inyo domes [Anderson et al., 1994]: 1) **Vent regions** are characterized by high relief, fractures and divergence of flow paths; 2) **Ridged areas** are characterized by regularly-spaced compressional ridges, with wavelengths between 10 and 15 meters and amplitudes of 1 to 4 meters; 3) **Jumbled regions** have more subdued topography and lack the characteristic structures present in vent and ridged areas; and 4) **Flow fronts** are the steep margins of the domes, with relief of tens of meters, and numerous nearly vertical cliff faces and zones of large blocky talus.

3. FIELD MEASUREMENTS

In order to understand the dominant mechanisms of radar scattering acting on the various surface units, topographic profiles at 25-cm intervals and boulder size

distributions were obtained at over 40 different vent, ridged, and jumbled zones on the Inyo dome surfaces [Plaut et al., 1994]. Examples are shown in Table 1. Data reduction of the topographic profiles included: detrending, rms height (standard deviation of surface heights), rms slope (standard deviation of point-to-adjacent-point slopes), and correlation length (offset for which autocorrelation function falls to $1/e$). Boulder size distributions were obtained along each topographic transect; the transects were typically 20-40 meters in length.

4. AIRSAR AND TOPSAR DATA

The NASA/JPL AIRSAR instrument was flown over the Inyo site in the summer of 1993. Three passes (at 25, 35, and 45-degree incidence angles) were obtained in the standard polarimetric mode, and several passes were obtained in the TOPSAR C-band cross-track interferometric mode. Some AIRSAR data were also available from an earlier campaign in 1989. HH backscatter behavior at C- and L-band was analyzed and interpolated to simulate S-band (12 cm) for comparison with SAR data from lava domes on Venus thought to be of similar origin (Figure 1) [Pavri et al., 1992]. The Inyo domes show an overall higher backscatter and shallower scattering "law" slopes than the Venus domes, which is consistent with the extreme degree of roughness that is observed in the field on the surfaces of the Inyo domes. Circular polarization ratios were also analyzed to identify the relative contributions of single- and double-bounce scattering mechanisms. L-band circular polarization ratios as high as 0.75 were common on the dome surfaces.

A preliminary TOPSAR integrated processing run was conducted on one of the 1993 passes. After removal of a cross-track ramp, elevation values appear quite consistent with published conventional topographic data. C-band SAR data were orthorectified and backscatter cross-sections were corrected for the scattering area of tilted pixels. A map of local incidence angle was also produced. New lava flow volume calculations were made for two of the domes that appear to rest on a relatively level substrate: Wilson Butte (0.0018 km^3) and Obsidian Dome (0.0175 km^3).

5. DISCUSSION

Field measurements (Table 1) indicate that the surfaces of these silicic lava flows and domes are among the roughest ever measured. Rms height values commonly greater than 50 cm, and rms slope values commonly greater than 30 degrees, exceed those measured on all but the roughest a'a basaltic lava flows [Campbell and Garvin, 1993]. Blocks larger than 20 cm normally cover over 50% of the surface, suggesting that large-scale facets predominate over subwavelength scatterers in the SAR backscatter measurements. HH backscatter cross-sections are also among the highest ever measured for dry rock surfaces. TOPSAR scattering-area corrections should allow direct comparison of scattering behavior of various geologic surfaces independent of the local pixel-scale scattering angle, which could bias conventional measurements on high relief surfaces such as these. Circular polarization ratios approaching unity suggest a major contribution of double-bounce to the scattering process, which is consistent with the angular, blocky appearance of many of these surfaces in the field. Few unvegetated natural surfaces display the observed characteristics of very high, nearly isotropic backscatter and a high circular polarization ratio.

6. ACKNOWLEDGMENTS

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7. REFERENCES

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Table 1. Roughness characteristics of selected lava flow surfaces from field measurements. Rms slopes for Venus domes are derived from Hagfors-modelled Magellan altimetry data.

Site	Rms Height, cm	Rms Slope, degrees	Correlation Length, cm	Arctan (h/l), degrees	Blocks, % < 10 cm	Blocks, % > 20 cm
Obsidian Dome, ridges	54.31	34.51	150.0	19.90	44	31
Osidian Dome, jumbled	30.09	35.52	50.0	31.04	10	64
Obsidian Dome, vent	82.29	40.01	125.0	33.36	7	73
Obsidian Dome, slabs	50.86	23.76	200.0	14.27	31	50
Cima, a'a channel	32.49	22.33	400.0	4.64	50	26
Cima, a'a margin	53.18	32.68	175.0	16.90	28	51
Kilauea, pahoehoe ¹	7.70	3.92	350.0	1.27		
Venus, steep-sided domes ²		<5.0				

¹from Campbell and Garvin (1993)

²from Pavri et al. (1992)

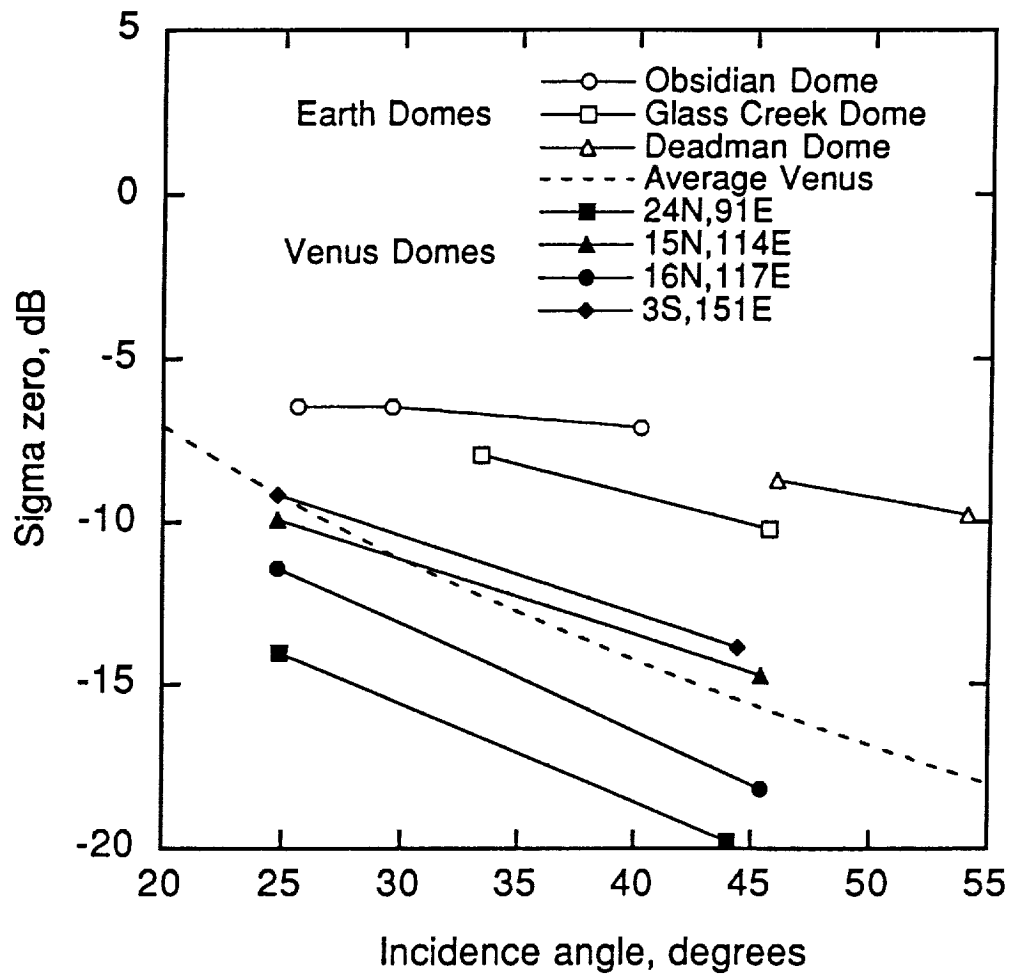


Figure 1. HH SAR backscatter as a function of incidence angle for the Inyo domes and similar features observed on Venus by Magellan. AIRSAR C- and L-band data are interpolated to simulate Magellan's S-band. Backscatter behavior indicates distinct differences in surface roughness of the Venus and Earth domes.