LITHOLOGIC CONTROLS ON AIRSAR SIGNATURES OF BEDROCK AND ALLUVIUM, AT LUNAR CRATER , NEVADA

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1. INTRODUCTION

Radar backscatter intensity as measured by calibrated synthetic aperture radar (SAR) systems is primarily controlled by three factors: local incidence angle, wavelength-scale roughness, and dielectric permittivity of surface materials. In order to make adequate use of radar observations for geological investigations of surface type, the relationships between lithology and the above characteristics must be adequately understood. In arid terrains weathering signatures (e.g. fracturing, debris grain size and shape, slope characteristics) are controlled to some extent by lithologic characteristics of the parent bedrock. These textural features of outcrops and their associated debris control radar backscatter to varying degrees. The quad-polarization JPL AIRSAR system allows sampling of textures at three distinct wavelength scales: C-band (5.66 cm), L-band (23.98 cm), and P-band (68.13 cm).

This paper presents a discussion of AIRSAR data using recent field observations of weathered felsic and basaltic volcanic rock units exposed in the southern part of the Lunar Crater Volcanic Field, in the Pancake Range of central Nevada (Snyder et al, 1972). The focus is on the relationship of radar backscatter at multiple wavelengths to weathering style and parent bedrock lithology.

2. GEOLOGIC SETTING

The Lunar Crater portion of the Pancake Range consists of Tertiary (31 to 25 my old) rhyolitic to andesitic volcanic rocks (Ekren et al. 1974) including andesitic and quartz latitic lavas, and a number of distinct welded and bedded tuff units displaying varying phenocryst and lithic contents and devitrification textures (Snyder et al, 1972). Basin and Range style tectonics strongly faulted the Tertiary volcanics and also isolated the drainage of the region. Nearby Lunar Lake playa is the result of this internal drainage. Pleistocene and Holocene basalt units extruded through a number of cones and NNE trending fissures (Scott and Trask, 1971; Snyder et al, 1972). The region has remained relatively stable during the Quaternary. Mass wasting has resulted in the development of extensive alluvial fans, and fluvial deposits, and recent aeolian activity has locally developped desert pavement.

Basalt outcrops in the area show relatively mature upper weathered surfaces, with well-developed desert pavements consisting of basalt cobbles 10-40 cm in diameter resting on an aeolian-derived soil of up to several meters in thickness. Felsic outcrop morphologies are highly variable, ranging from low rounded hills with relatively thick soils to cap-rocked mesas with fresh bedrock exposures and steep cliff faces as high as 250 m. Alluvial deposits are predominantly sandy gravels, although several washes contain large boulders reflecting high-energy depositional environments.

3. FIELD OBSERVATIONS

Within the area, two types of terranes were the focus of field observations. The first is a plateau occupied by a flat lying rhyolite ashflow exposed largely as in-situ debris.The top few metres of the ashflow are strongly welded and dissected into metre-sized columnar joints. Their weathering products form three domains with distinct surface morphologies: i) metre-size boulders (core stones) and large exposures of spheroidally weathered bedrock with dispersed Juniper trees, ii) areas of cm-size debris with sparsely dispersed shrubs and, iii) areas of decimetre-size slabs with sparsely dispersed shrubs. All three domains display unique SAR signatures and as a whole are characteristic of the upper most part of the ashflow. Immediately below the columnar joints is a more fractured and friable part of the ashflow which is exposed along the valleys dissecting the plateau. This surface is characterised by loose cm-size debris overgrown by denser and larger shrubs than observed at the top of the plateau. Table 1 summarize the characteristics of the unconsolidated material and vegetation for both parts of the ashflow. The controls on the SAR signals by surface characteristics are discussed below.

The second terrain consists of alluvial fans with older areas of desert pavement dissected by active channels. The fans material varies in lithological makeup and surface roughness depending on provenance. The majority of clasts are derived from felsic ashflows, which is the bedrock for most of the mesas, making the field determination of clast provenance a difficult task. Locally, however, fan surfaces displaying subtle differences in average clast size due to specific source regions can be seen in the SAR data. Table 2 provides a description of fan surfaces which are difficult to separate in the field but which can be distinguished using the polarimetric SAR signatures.

4. DATA ANALYSIS

__Alluvial fans__

HH and VV polarizations

The mapping of alluvial fans was conducted using C-band data because of its sensitivity to the range of clast sizes dominant on these surfaces (0.5-1.5 cm). The effect of surface roughness on C_{HH} and C_{VV} returns is very strong particularly in the case of smooth surfaces (rms surface heights less than 1 cm). Subtle differences in mean clast size, in this case 0.5 cm and 1.5 cm, are detectable and can be related to the provenance of the material in the fans. L and P-band images did not improve the mapping of most fans but did outline portions of fans dominated by boulders deposited in a high-energy environment.

The drainage channels cutting the fans are imperceptible in C band. The channels are dominated by sand and thus are smoother than surrounding fans but these differences in roughness are not detectable because the channels are subpixel in size. The channels are easily observed in L and P band wavelengths because the presence of moisture at depth (< 4 cm) is detectable resulting in enhanced backscatter.

HV polarization

Images of the cross-polarized signals portray information largely related to the distribution of vegetation density and type (or size). Fan areas occupied by grass are distinct and show the weakest signals at all bands. Fan areas with shrub density (< 15%) and size (diameter < 35 cm) such as described in table 2 produce weak signals and signal variations in C band. Distinct signatures in C and L band were observed for a site with 30% shrubs with average crown diameter of 45 cm. This extent of vegetation cover is easily mapped using a combination of C_{HV}, L_{HV} and P_{HV} and is typical of widespread fan areas located in the downslope proximity of the plateaus. The vegetation on the fans contributes minimal HH and VV returns and does not mask the fan roughness variations observed on the like-polarization images.

__Plateau__

HH and VV polarizations

Although mapped by Snyder et al (1972) as a single map unit, the two subunits of the ashflow described in table 1 display dramatically different radar signatures related to weathering style. These two units illustrate the use of radar for lithologic discrimination based on surface roughness and vegetation. Unit 1 forms an erosional cap to the mesa and is characterized by a predominance of rock debris. The three geomorphic domains of unit 1 span a range of surface roughness from smooth bedrock surfaces and relatively smooth pebble pavement to irregular surfaces rich in rock slabs. These surfaces respectively produce stronger returns in C and P band. Rock outcrops with steep topography provide strong returns independent of wavelengths. In contrast unit 2 shows high returns in C and L-band where significant L-band return from the woody component of the shrubs appears to be contributed to the return of the fine pebble surface.

HV polarization

Large, 2-3 m high, Juniper trees produce strong returns in P-band, a radar signature diagnostic of unit 1. Unit 2 produces strong returns in L band because of the high concentration of relatively large sagebrushes and saltbushes which have thick, woody stems and branches (table 2).

5. CONCLUSIONS

For the southern Lunar Crater Volcanic Field, analysis of SAR imagery and field observations indicates that the radar signatures of alluvial fan surfaces and weathered bedrock are largely controlled by surface roughness and the nature of the vegetation cover. Because these characteristics vary with lithology, it is possible to use the frequency and polarimetric information to map lithology and alluvial fans.

In this site we were able to successfully separate 3 types of alluvium in the depositional flat based on a combination of roughness scale and vegetation type. These characteristics appear to be related to material provenance.

On the plateau, we were able to discriminate different weathering styles of the same lithology, which are indicative of different levels (depths) of erosion within the ashflows. We are presently evaluating whether variations in weathering styles within an ashflow can be related to variations in degree of welding.

6. REFERENCES

Ekren, E., W. Quinlivan, R. Snyder, and F. Kleinhampl, 1974, Stratigraphy, structure, and geologic history of the Lunar Lake caldera of Northern Nye county, Nevada, Journal Research U.S. Geological Survey 2(5), pp. 599-608.

Scott, D.H. and N.J. Trask, 1971, Geology of the Lunar Crater Field, Nye County, Nevada, USGS Prof. paper 599-I.

Snyder, R.P., E.B. Ekren and G.L. Dixon, 1972, Geologic map of the Lunar Crater quadrangle, Nye County, Nevada, USGS Misc. Inv. Map I700.

7. TABLES

Table 1. Surficial characteristics of the ashflow plateau

Unit 1(mostly derived from columnar joints):

- Domain 1 (fig. 1, left of letter a): bedrock displaying granite weathering, 5-10%* cover of juniper trees 3 m in height with average trunk diameter of 7-12 cm.
- Domain 2 (fig. 1, left of letter b): pavement of densily packed 1-2 cm size rounded fragment, 20% shrubs averaging 50 cm in height and 30 cm in diameter. Maximum branch diameter of 1-2 cm.
- Domain 3 (fig. 1, left of letter c): pavement of flat slabs with an average area of 25 x 25 cm and up to 50 x 100 cm, which occupy approximately 23% of the surface, and set in a matrix of 0.5-1.5 cm size angular clasts. Vegetation is similar to that observed in domain 2.

Unit 2 :

- The unit (fig. 1, below letter d) consists of a loose surface, 2-3 cm deep, made up of fine rubble (0.5-2 cm in size) covered to 30-40% by sage shrubs. Shrubs are in average 1m in height, 0.75m in diameter, with a trunk diameter of 6 cm.

*Refers to estimates in plane view

Table 2. Surficial characteristics of the alluvial fans

- Fan 1 (fig. 1, letter e): 5-10% grass, 8% shrubs with an average diameter of 25 cm. Remainder is a weakly compacted surface two thirds of which are clast < 0.5 cm in size and one third of which are fines (< 1mm).

- Fan 2 (fig. 1, letter f): 15% shrubs with an average diameter of 35 cm and trunk size of 1-2 cm. The remainder is a compacted surface largely dominated (< 90%) by rounded clasts of uniform size (1-1.5 cm).

- Channels consist dominantly of loose sand (beyond a decimeter) with few cm clasts and rare boulders. Moisture was present at 4cm depth and vegetation is vigorous. Bushes are typically 50cm in height.

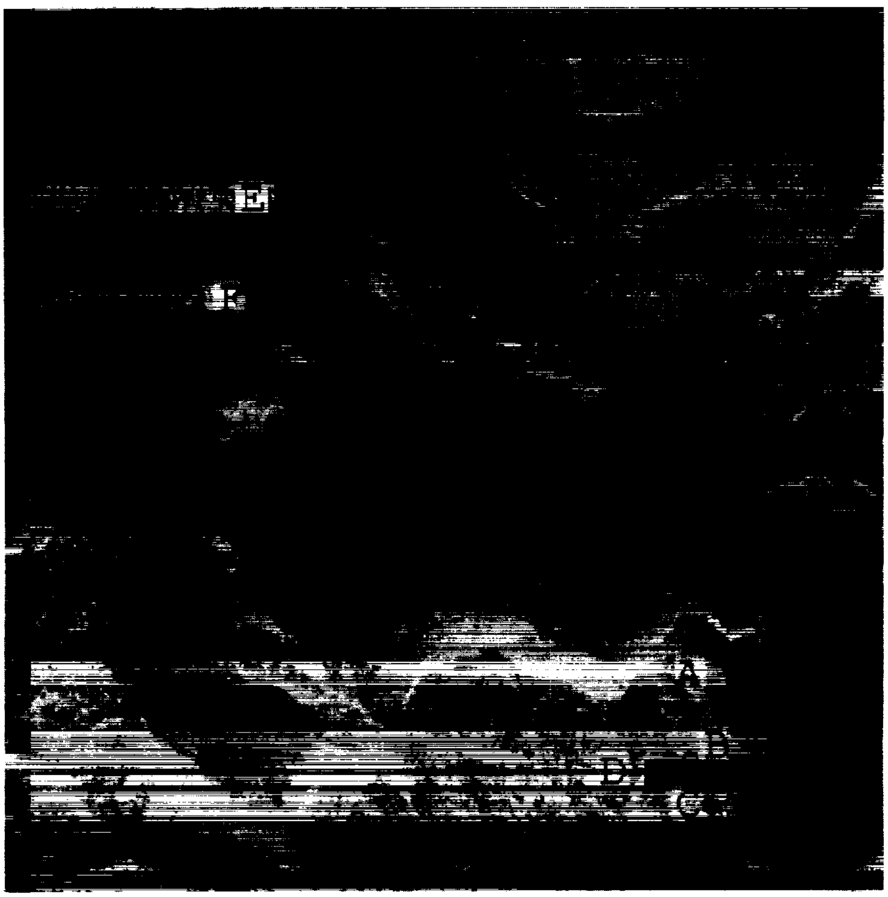

Figure 1. AIRSAR C-band HH image in slant range, illumination from the top (northwest). Calibration of phase, amplitude and co-channel gain imbalance was conducted using trihedral corner reflectors and assuming the absence of relief. No attempt was made to calibrate the data with the use of a DEM. Thus our efforts have focused on the analysis of SAR signatures for relatively flat areas. Approximate scene dimensions of 9 x 9 km. Letters refer to locations discussed in the text and described in the tables.