SHORT COMMUNICATIONS

Preliminary Analyses of SIR-B
Radar Data for Recent Hawaii Lava Flows

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The Shuttle Imaging Radar (SIR-B) experiment acquired two L-band (23 cm wavelength) radar images (at about 28° and 48° incidence angles) over the Kilauea Volcano area of southeastern Hawaii. Geologic analysis of these data indicates that, although aa lava flows and pyroclastic deposits can be discriminated, pahoehoe lava flows are not readily distinguished from surrounding low return materials. Preliminary analysis of data extracted from isolated flows indicates that flow type (i.e., aa or pahoehoe) and relative age can be determined from their basic statistics and illumination angle.

Introduction

Two synthetic aperture radar (SAR) images were acquired by SIR-B over southeastern Hawaii. The summit area and Southwest Rift Zone of Kilauea Volcano were the primary targets. The first, at an incidence angle of 28°, was acquired over the designated target area at approximately 4 a.m. Hawaiian Standard Time on Thursday, 11 October 1984. The second, acquired over the target area 24 hr later, was at an incidence angle of 48°.

Previous remote sensing investigations have indicated that radar imagery can be used in identifying and mapping volcanic units (Blom et al., 1982; Dellwig, 1969; Elachi et al., 1980; Malin et al., 1978; Schaber et al., 1980). Supplemented by field measurements of soil moisture during the mission and postflight surface roughness measurements, the SIR-B data for Hawaii are currently being used to
investigate lava flow morphology and eruptive history. Preliminary analyses of these data have permitted the delineation of several distinct textural units and topographic features in the Kau Desert/Kilauea area.

Observations

SIR-B imaged an area of approximately 3500 km² on southeastern Hawaii [inset Fig. 1(a)]. The pristine, unvegetated nature of volcanic terrains in the Kilauea/Kau Desert district makes this region ideal for delineation and interpretation of lithologic features. The Kau Desert extends almost 30 km southwestward from the summit of Kilauea Volcano to the ocean. As corroborated by our soil moisture measurements, the environment in the Kau Desert is moderately wet with up to 125 cm of rain per year (University of Hawaii, 1983), but rainfall in this area has been acidified by fumes produced at the summit of Kilauea. Vegetation is

FIGURE 1. (a) Sketch map showing the location of lava flows, airfall deposits, and structural features in the summit and Kau Desert area of Kilauea Volcano. Aa flows are shown in solid shading, and pahoehoe flows are outlined. Symbol (A) marks the transition from aa to pahoehoe on the December 1974 lava flow. Other letters indicate the September 1982 pahoehoe flow (B), the solidified lava lake in the floor of Kilauea Iki pit crater (C), the area covered by the 1790 ash deposit (dot-dash line at (D)), and the younger ash deposit located downwind of Kilauea Iki in the Devastation Trail area (E). The approximate limit of numerous ejecta blocks created by the 1924 phreatic eruption of Halemaumau is shown by the dotted outline at (F). The inset shows the location of the 28° and 48° SIR-B radar images acquired over the Island of Hawaii; radar illumination is toward the southeast. (b) Segment of SIR-B radar image acquired over the Kilauea/Kau Desert area at an incidence angle of 48°. Major units in this area are identified in (a).
therefore scarce in the northeastern region of the Kau Desert (near Kilauea), increasing only slightly in quantity to the southwest.

Surface materials in the Kilauea/Kau Desert area consist predominantly of airfall deposits and relatively young basaltic lava flows. The location and corresponding radar responses (at 48° incidence angle) of historic volcanic units in this area are illustrated in Figs. 1(a) and (b). The brightest features on the radar image correspond to aa lava flows, which are known to be significantly rougher than surrounding terrain. While aa flows in this region are only 10-60 years old, numerous aa flows further to the south also have moderately high backscatter despite ages in excess of 1500 years. Examination of the distribution of flows in the Kau Desert (Holcomb, 1980) reveals that aa flows can be distinguished on SIR-B images regardless of age and/or vegetation cover.

Pahoehoe lava flows are the primary example of volcanic units which are not readily distinguishable on the images. For example, the December 1974 flow erupted as pahoehoe but changed to aa about 5 km from the vent [A, in Fig. 1(a)]. In the SIR-B data, only the aa portion of this flow is visible. Field measurements of pahoehoe and aa segments of the December 1974 flow show significant differences in roughness. Further examples of pahoehoe lava flows that are virtually unrecognizable on the radar images are the September 1982 flow (B) and the solidified lava lake on the floor of Kilauea Iki (C). Other low-return units include an extensive layer of ash and volcanic debris produced during the 1790 explosive eruption of Kilauea (D), and a younger pyroclastic deposit resulting from the 1959 eruption of Kilauea Iki, in the Devastation Trail area (E).

Although topographic features are often preferentially enhanced by radar, some positive-relief topographic features that are not readily detectable on the SIR-B radar images of the Kau Desert include: Mauna Iki, a broad, low (40-m) lava shield; the Kamakaia Hills, a complex of small (30-m) cinder cones; and the Kaoiki Pali, a southeast-facing scarp at the base of Mauna Loa. Similarly, a number of negative-relief features, such as fractures of the Southwest Rift Zone (ranging from centimeters to several meters in width), cannot be readily identified.

The summit of Kilauea is characterized by an oblong collapse caldera (4 × 3.2 km), a smaller (900 m) interior pit crater (Halemaumau), and is bordered to the northeast by a high-return rain forest. Most of the intracaldera eruptions produced pahoehoe flows, causing the interior of Kilauea Caldera to appear dark in the radar images. An exception to this is the lighter tone of the 1924 phreatic deposit surrounding Halemaumau (F). This deposit consists of particles ranging in size from sandy ash up to 2-m-high boulders (Jagger and Finch, 1924) emplaced at radial distances in excess of about 3 km from the rim of Halemaumau.

**Analysis**

Nineteen previously mapped aa and pahoehoe flows were isolated on the 28° SIR-B data (the 48° data were not yet available) and statistically analyzed for trends which might serve to discriminate between flow types. Before reviewing these trends, a short discussion is provided to clarify their significance.
Radar image formation is an inherently noisy process. The signal received at the antenna is noisy because it is the summation of the complex return voltage from the many discrete scattering centers within a resolution cell. This noise, commonly called fading, produces a wildly fluctuating signal due to constructive and destructive interference. The fading return from an ideal surface will exhibit a Rayleigh probability density function (pdf) if the voltage magnitude is recorded. A nonideal surface is not a Rayleigh scatterer, and the fading pdf may be significantly different.

SIR-B images represent the sum of four separate observations of each point on the ground, called independent looks, with the average returned power from each look contributing to the sum; the voltage magnitude of this sum is recorded in the images produced at JPL (Jet Propulsion Lab, Pasadena) instead of the return power (note that the voltage magnitude is just the square root of the return power). For an ideal surface (i.e., Rayleigh scatterer), the pdf of the sum of four independent looks is a $\chi^2$ distribution with eight degrees of freedom: an example of this type of pdf is plotted as a smooth curve in Fig. 2. A $\chi^2$ distribution with six degrees of freedom corresponding to the sum of three independent looks is plotted in Fig. 3.

Histograms of typical aa and pahoehoe flows are plotted with the theoretical models in Figs. 2 and 3. Comparison between the histogram of an aa or pahoehoe flow and a theoretical pdf (such as that for an ideal Rayleigh scattering surface)

**CHI-SQUARED MODEL (N=4)**

**HAWAII NO. 10 (AA)**

**DATA** NO. MEAN = 79.3, VARIANCE = 1548.5

**FIGURE 2.** Histogram of one aa flow. The histogram is plotted and compared with an $N = 4\chi^2$ probability density function having eight degrees of freedom. The means and variances are identical for both curves.
provides information about the flow texture because histogram shape is potentially diagnostic of a scattering surface and may be indicative of its roughness. For the purpose of comparing the histograms of lava flows to theoretical models such as those in Figs. 2 and 3, the SIR-B data have been converted back to power and plotted with the models.

Examination of Figs. 2 and 3 reveals a general correspondence between the histograms and the theoretical pdfs. Figure 2 plots the histogram of an aa flow with the pdf representing the sum of the return power from 4 independent looks at an ideal Rayleigh scattering surface. Figure 3 plots the histogram of a pahoehoe flow with the 3 independent look pdf from the same theoretical surface. Although the SIR-B data represent the average of 4 looks, they are not the average of 4 independent looks because the antenna pattern is not an ideal square shape and the shape of the antenna pattern weights each look in the average. A better estimate of the number of independent samples averaged is thus less than 4. An accurate estimate has not yet been determined because it is not crucial to the results presented here, but the number of independent looks for SIR-B data is closer to 3 than it is to 4.

Observe in Fig. 2 how the 4-independent-look pdf is in general agreement with the histogram of an aa flow. This observation implies that an aa flow is not an ideal rough surface because the histogram is more symmetric than would be the pdf from an ideal surface. Note in Fig. 3 how the 3-look-pdf appears similar to the pahoehoe histogram. It appears from this that a pahoehoe flow more nearly ap-
proximates an ideal surface than does an aa surface since the theoretical model plotted in Fig. 3 is closer to being the pdf for an ideal surface imaged by SIR-B. It is concluded therefore that at this wavelength and resolution scale aa flows do not follow Rayleigh’s scattering model (the pdf is too symmetric), but pahoehoe lava flows might be close to ideal surfaces. These observations are supported by field measurements of the surface roughness of both aa and pahoehoe flows. These
roughness measurement data are being analyzed to aid construction of theoretical models which will represent the relationship between radar return and flow rheology.

An additional statistical analysis of the nineteen flows was conducted to determine the effect of the age of a surface on radar backscatter. These flows range from 10 to 1300 years in age and, except for the two oldest flows, are pristine. Figure 4 is a plot of age (Holcomb, 1980) versus the data number (DN) mean of each flow. Figure 5 is a similar plot for age versus the DN variance. These figures indicate a relationship between flow age and surface micro-roughness at L-band. This trend is strengthened by discounting the two anomalous points representing highly vegetated aa flows; these appear to be rougher than would be expected from their age. Extrapolation of these trends to old and/or vegetated flows is clearly unjustified due to the narrow range of flow ages investigated to date.

Summary

Preliminary geologic analysis of SIR-B images have permitted the delineation of several distinct surface units and topographic features in the Kilauea Volcano/Kau Desert area. In addition, initial analysis of the basic statistics of the data for isolated lava flows suggests that radar can be used both to discriminate aa from pahoehoe, and to separate each flow by age.

The extreme roughness and blockiness of aa flows produce both distinctively high returns on radar images and histograms characteristic of nonideal scattering surfaces. Pahoehoe flows, by contrast, are smooth, low-return features which are difficult to distinguish from surrounding radar-dark materials, particularly ash, and appear to be nearly ideal scattering surfaces. Despite our field observations which show that these flows have as much as 50 cm of vertical relief, only the rougher aa flows can be easily identified on SIR-B images. This has important implications for the use of space-borne radar for volcanological studies. For example, without detailed field knowledge, both the number and length of several Hawaiian flows would be underestimated, as would be the relative abundance of effusive eruptions. Pyroclastic volcanism, represented by ash deposits with low radar backscatter, would appear to be a more important style of volcanism near Kilauea Caldera than is warranted. In addition, many constructional features, such as cinder cones and low-relief lava shields would not be detected, again suggesting that effusive or strombolian activity was not as significant as large-scale explosive eruptions.

A relationship between flow age and surface microrelief at L-band is suggested for both aa and pahoehoe lava. Analysis of the mean and variance of the data numbers extracted from isolated aa and pahoehoe flows serves to distinguish them from each other and to categorize them on the basis of age. This is true even though the initial identification of pahoehoe flows is difficult. In addition, histograms of the two different types of flows suggest that a phoehehoe lava represents a nearly ideal scattering surface, but aa does not. Investigation is continuing to determine the relationships between the roughness and dielectric properties of a surface and flow rheology.

The Hawaiian Volcano test site provides an ideal opportunity for studying
the radar image representation of pristine lava fields. The refight of SIR-B should have this test site as a prime target for important multilook angle data (especially at the steeper incidence angles to take advantage of the increased sensitivity of radar backscatter to slope) for aiding identification of pahoehoe flows and subtle topographic features, and for providing additional information for the functional relationship between the radar return and flow rheology. More immediately, SIR-B images may be reprocessed to enhance subtle topographic features, and to emphasize low return features (Matthews et al., 1984). In the more distant future, the addition of multiwavelength and multipolarization capabilities of the SIR-C experiment (currently scheduled for a mid-1989 flight) to the multi-incidence angle capability explored by SIR-B may improve distinguishing pahoehoe flows from other geologic units, such as ash deposits, that have a low radar return, and may improve our knowledge of the functional relationship between radar return and flow rheology.

We acknowledge support from NASA grant number JPL 95692S. The advice and assistance of S. Rowland and scientists at both the Hawaiian Volcano Observatory and National Park Service were also appreciated during the collection of the surface roughness and soil moisture data.

References


Received 31 December 1985; revised 4 February 1986.