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A GEOSCIENCE EVALUATION OF MULTIFREQUENCY RADAR IMAGERY OF THE PISGAH CRATER AREA, CALIFORNIA

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A GEOSCIENCE EVALUATION OF MULTIFREQUENCY RADAR IMAGERY OF THE PISGAH CRATER AREA, CALIFORNIA

by

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ABSTRACT

The Pisgah Crater test site has been imaged by several different radar systems. Although simultaneous imaging by K-, C-, and P-band radars has not been realized, cautious comparison (recognizing the influence of variations in system and surface parameters) of available, non-simultaneously recorded imagery point to the value of simultaneous imaging by long and short wavelength systems. The imagery evaluated has well documented the wavelength dependence of the return signal from some cultural and natural phenomena. Variations in return were primarily a function of surface roughness although some penetration by long wavelength radar was also demonstrated.

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INTRODUCTION

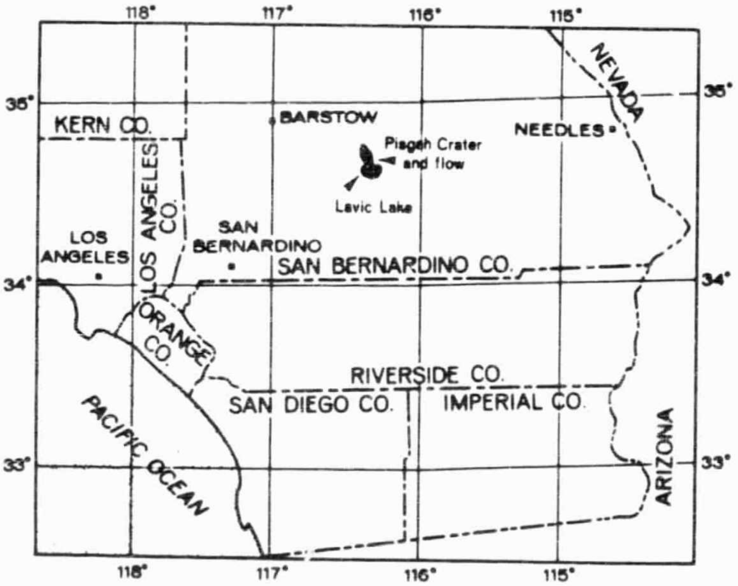
Cursory examination of radar imagery of different wavelengths during the course of previous investigations suggested that simultaneous imaging of a region with several frequencies of radar might provide a great deal of information which would not otherwise be revealed. Unfortunately, there is little multifrequency radar imagery available for systematic evaluation for geoscience content. At the present time, in order to evaluate long-wavelength imagery, it becomes necessary to compare long-wavelength imagery of one system with short-wavelength imagery of other systems recorded at different times. Thus system and target parameters show a minimum of similarity. Systems, aircraft elevation, depression angle, look direction and a host of other parameters are greatly diversified, and conditions in the target area (climatic, vegetative, etc.) also are without calibration. Only the general geologic state of the terrain can be assumed to remain constant over a relatively long period of time.

Fully aware of the shortcoming of any conclusions drawn from such an investigation, the author examined radar imagery of three systems and three wavelengths from Pisgah Crater, California area (Figure 1) in order to tentatively evaluate multifrequency imaging of a geologic site. The conclusions reached in this investigation are open to criticism, in which no one will join more readily than the investigator.

Aerial photographs (Figure 2) used for control and comparison are included in Army Map Service (AMA) project 145, Roll M71, the area having been flown on 18 December 1954. Minor post-photography, pre-radar imaging changes are obvious in the locations of cultural features, but it is assumed that the geologic and geographic environment has remained essentially unchanged between 1954 and 1965 except in one small area

FIGURE 1.

Index Map Showing the Location of the Pisgah Crater-Lavic Lake Area, California



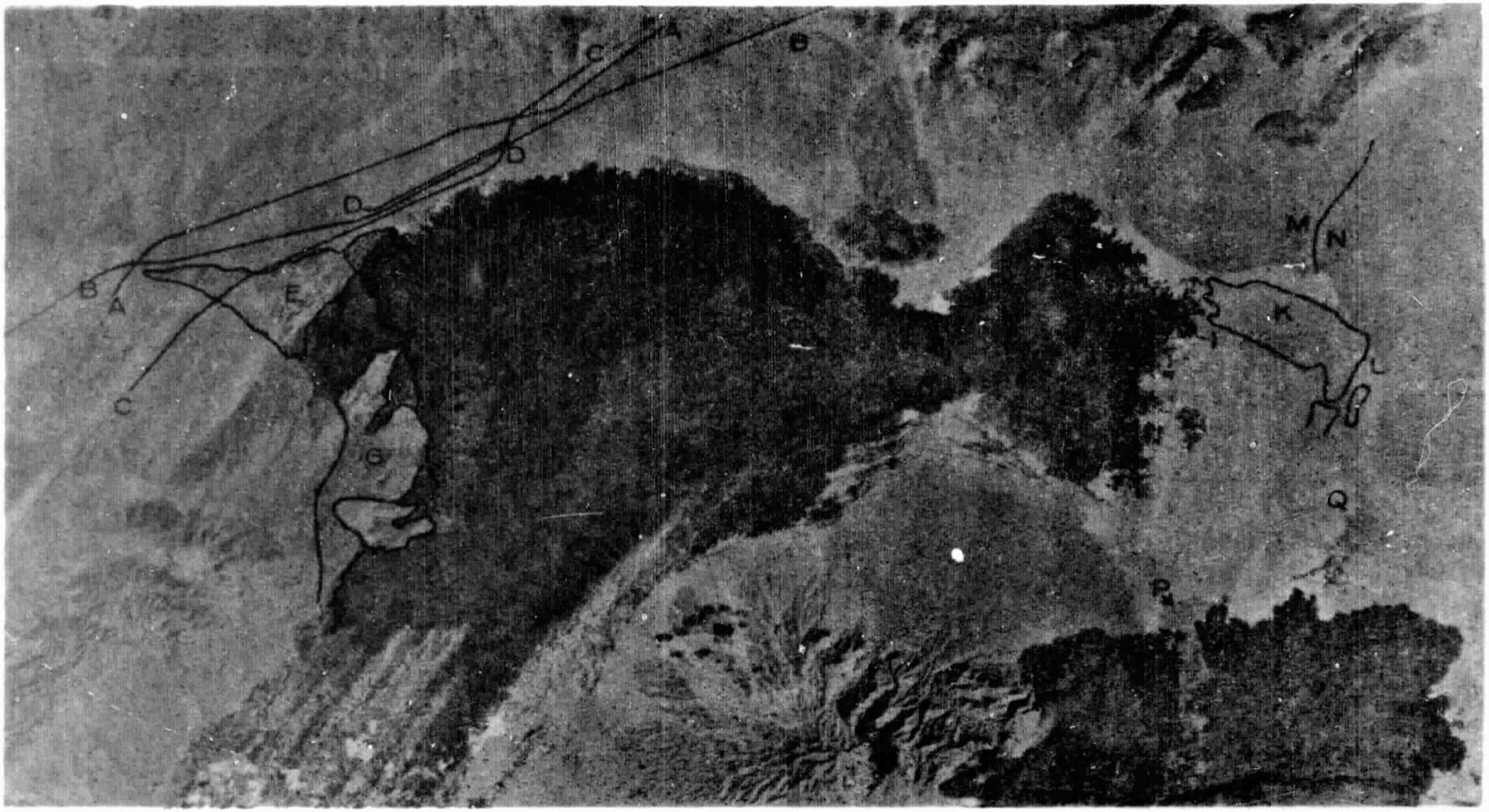


FIGURE 2. PISGAH CRATER AREA, CALIFORNIA

(FOR IDENTIFICATION OF LETTERED FEATURES, SEE TABLE 1)

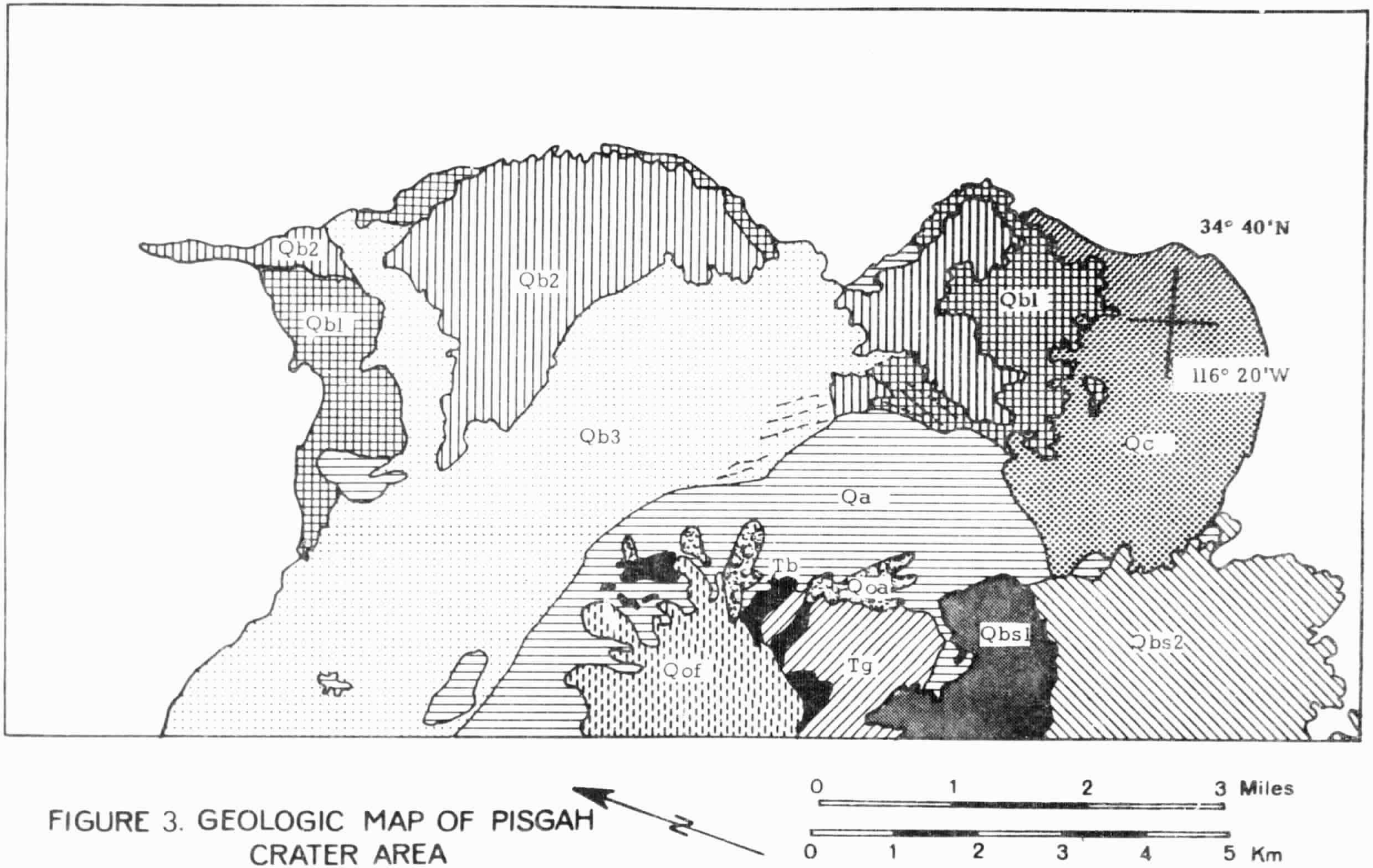


FIGURE 3. GEOLOGIC MAP OF PISGAH CRATER AREA

Figure 3

(Geologic map modified from T.W. Dibblee, Jr., Preliminary Geologic Map, Pisgah Crater and Vicinity, California, unpublished map, 1965).

Explanation:

Pleistocene and Recent

- Qa - Alluvium
- Qb - Pisgah lava flow
  - Qb1 - First eruptive phase lava
  - Qb2 - Second eruptive phase lava
  - Qb3 - Final eruptive phase lava
- Qc - Clay

Pleistocene

- Qoa - Older alluvial gravel
- Qbs - Sunshine lava flow
  - Qbs1 - Lavic lava flow
  - Qbs2 - Sunshine Cone lava flow
- Qof - Older fanglomerate

Oligocene or Miocene

- Tb - Basalt
- Tg - Gravel

at the southeastern end of Lavic Lake (page 14). Weather records at Dagett, California (30 miles to the northwest) do not indicate any appreciable rainfall prior to any of the overflights so that it is further assumed that moisture content of surface materials has no influence on the return signal.

The imagery examined was obtained on three flights over the Pisgah Crater NASA test site.

Agency	System Designation	Band	Wavelength	Flight
NASA	AN/APQ-97	K	----	November 1965
Air Force Avionics Laboratory	AN/APQ-55	Ka	0.84cm	November 1964
Naval Research Laboratory (NRL)	------	C	6.73cm	October 1965
Naval Research Laboratory (NRL)	------	P	70.00cm	October 1965

GEOLOGY

The geologic setting (Figure 3) has been adequately described for purposes of this study by Gawarecki (1964) and Dellwig et al. (1965). Detailed geologic mapping was accomplished by Wise (1966), at which time the lavas of the Pisgah field were separated into flows of three distinct eruptive phases.

Gawarecki (1964) describes the area as follows:

> The Pisgah Crater and lava flow area is located in the Mojave Desert about 38 miles (61km) east-southeast of Barstow, California. U.S. Highway 66 skirts the northern part of the area and provides easy access via asphalt-paved and dirt roads to the Crater and to the perimeter of the flow.
>
> The main flow area is about 14 miles (23km) long, northwest to southeast, and is 4 miles (6.4km) across at its widest point near Pisgah Crater. The main scene of interest is about 32 square miles (83 sq. km) in area. Pisgah Crater, the most prominent landmark on the flow, is about 320 feet (98m) high and 1600 feet (488m) in diameter at its base. The flow is rugged, but not of much relief. At the southeast end of the flow

is Lavic Dry Lake, a playa that is about 2 miles (3.2 km) in diameter. To the west of Lavic Lake is the Sunshine Cone basic lava flow of about 6 square miles (17 square km) in an area that is associated with a north-northwest-trending fault zone. It slopes toward the dry lake from an average elevation of 2700 feet (823 m) to about 1900 feet (579 m). Sunshine Cone, a 160 foot (49 m) high cinder cone, is at the west margin of the flow. Its elevation of 3121 feet (951 m) above sea level is the highest on this particular flow.---

The area is well within the Basin and Range physiographic province and is one of the many centers of recent volcanic activity which lie on broadly alluviated valleys and playas across the central part of San Bernadino County. The Pisgah flow is a composite of many thin basaltic lava flows.---The top of the flow area is composed of two general textural types of lava; pahoehoe, or ropy lava, and aa, a rough, jagged, clinkery lava. Some of the pahoehoe assumes a blocky appearance bordering on the aa type. The pahoehoe type is medium dark gray and its smoother undulating surface tends to accumulate small pockets of windblown silt and sand. Sparse brushy vegetation is found on its surface in places. The aa is a dark gray to black color and its extremely rough surface absorbs most of the light that falls upon it. The jagged nature of this type of lava inhibits traction of windblown detritus across its surface. In the vicinity of the crater a number of cones resulting from breached lava tubes are found beneath pahoehoe type lava.---

Pisgah Crater is made up mostly of clinkery cinders and small bombs with occasional beds of agglutinate from spatter material. The cinders are found in distinct color segrations of medium dark gray or grayish red. The floor of the crater is formed of solidified basalt of the pahoehoe type.

The Sunshine Cone lava flow which is west of Lavic Dry Lake is somewhat smaller than the Pisgah Flow. It is made up of two different lavas, a dark gray basalt on the south and a medium gray basalt or andesite on the north. A tonal difference between the two rock types is quite noticeable on aerial photographs. Topographic relations indicate that the lava flow on the south is the younger of the two.

Wise elaborates on this description:

> The Pisgah lava field was formed in three distinct eruptive phases each separated by a fairly long period of time. Separation of flows into each phase is based solely on the texture of the phenocryst minerals.
>
> Activity began with the building of a cinder cone (low hills north of what is now the main cone), and lava issued from vents near the cone. Lava flowed only 1.5 miles (2.4 km) north but extended 5 miles (8 km) southeast to Lavic Lake, where it covered nearly five square miles of the lake bed area. Two long flows went down the gentle drainage to the west.---In most localities the top of the lava is only a few feet above the surrounding alluvium. The cinder cone has been almost destroyed by subsequent erosion.---
>
> After a long period of quiscence lava again rose through apparently two separate conduits. One carried most of the volatiles, and a cinder cone was built where it broke through to the surface (about 1000 feet (305 m) south of the site of the older cone). Lava rising in the other conduit encountered a thick lava flow through which it failed, at first, to penetrate. The older basalt was domed upward 150 feet (46 m) by the new magma, which possibly formed a small laccolith. The older lava cover finally broke and lava welled out of several vents around the dome. More upwelling buckled earlier lava (but not that which had been erupted during this phase), forming a "tongue" between the dome and the cinder cone.
>
> These lavas were as voluminous as those in the first phase -- flows extended 11 miles (17.7 km) to the west, 2.5 miles (4 km) north, and 4 miles (6.4 km) to the south. The lava surface is largely aa, though pahoehoe surfaces are on most of the long westward flow. Wind blown sand and alluvium covered the lavas locally.---
>
> Again magma rose in two columns -- one forming the present cinder cone and the other erupting only lava. The lava vents were over one mile south of the cinder cone, and there was no accompanying cinder activity. Lava also issued from a vent on the side of the cinder cone and from a small vent on the "tongue," formed during the second phase.
>
> These flows extended only about half as far as the earlier ones. Interesting features of these flows include the repeated piling against an alluvial

> fan to the south. The flow surface is pahoehoe over its entirety, though pressure ridges and tumuli are common.
>
> Intensive discharge in the wash to the south of the lava flow has brought enough alluvium to cover a portion of the flow. Wind blown sand easily accumulates on the pahoehoe surface, giving the illusion that the aa flows (second eruptive phase) are the youngest.
>
> The Sunshine Cone lava field consists of two flows. The older, ---, probably antedates the first eruptive phase at Pisgah, based upon the relative state of erosion. The faulted remnant of an eroded cinder cone marks the area from which the --- flow originated.--- Original surface irregularities have been almost completely removed by weathering and erosion.
>
> The --- (younger) flows issued from Sunshine Cone probably sometime between the first and second Pisgah eruptive phases.--- Original surface irregularities of the flow are only partially removed by weathering and erosion.

To this, Dellwig, et al. (1965) adds

> Lavic Dry Lake measures approximately 3.5 kilometers in an east-west direction and 2.4 kilometers in a north-south direction. The lake is limited to the north and southwest by basaltic lava flows against which Lavic Lake abruptly terminates; in other directions it is bounded by alluvial fans which slope gently upward and away from Lavic Lake to the base of adjacent mountains.--- The playa surface in gross aspect is a hard, dry, compact (argillic) crust consisting of approximately 79% clay, 20% granular components, 0.2% accessory minerals and a trace of saline minerals (Neal 1965). There are some scattered areas of soft, dry, porous, puffy surfaces and several large areas in which giant contraction polygons have developed.

Mounds of fine-grained windblown sediments at the base of greasewood or sage

> are common both in the marginal areas of the playa and also on the adjacent alluvial fans. The upper surface of the lake, with the exception of the centers of bomb (military ordnance) craters and the area in and adjacent to the giant contraction fissures, is uniformly dry. However, shallow soil samples across the lake display a detectable

> change in moisture content. The lakebed surface is relatively flat, somewhat windscoured and covered throughout with mudcracks which developed during several stages of dessication.
>
> Lavic Lake mudcracks may occur as a single pattern of sharply defined cracks or may be superimposed upon an older, large pattern which has generally been modified by wind or water activity. Polygon diameter for the smaller crack pattern reaches a maximum of 11 cm, whereas the older, larger polygons may be as much as 35 cm in diameter. The superposition of the younger, small crack pattern upon the older, large pattern produces a surface with relief up to 40 mm, the superposed relief of the younger cracks being only 8-10 mm.
>
> Giant contraction polygons follow a trend which in general parallels the margin of the lake. Polygon diameters measure tens of meters. These giant polygons are outlined by a central depression, which averages 30 cm wide. The central depressions are bounded by low ridges of approximately the same width (30 cm). The ridges are puffy and the depressed zones are soft and wet. The entire area of giant polygons is generally darker than the surrounding flat lake bed, apparently because of higher salt content and moisture. These depressed zones within the area of giant polygons, apparently act as capillary zones along which moisture migrates upward. The polygonal pattern is easily detectable on aerial photos, and by the 'high' return on infrared imagery.

Finally, Gawarecki points out that:

> There are at least two ages of alluvial fans in the area. The older fan is generally a light olive-gray gravel with up to boulder-sized material composed of copious amounts of basaltic fragments derived from older flows, felsite, quartzite, and quartz. The removal of fine detritus by wind and water erosion is responsible for a concentration of darker material on the surface. The main out-crop area is the dark-toned material just west of the crater access road. Windblown sand covers much of its surface area.
>
> The younger alluvial fan material is a similar heterogeneous conglomerate that is derived from the present topographic highs. It is yellowish gray color because of its higher content of sand-sized fraction.

IMAGERY EVALUATION

Areas and features of interest, both cultural and geologic, are tabulated in Table 1. Two particularly significant observations emerged from the study: (1) Windblown silts and sands were penetrated by the long wavelength radar (P-band), the return signal apparently being from a partly buried lava. (2) The alluvial fan on the southwestern side of Lavic Lake, although well defined on K-band radar imagery, was not delineated on the P-band image. The surface of the fan was composed of fragmental material, 85% of which was under 5 cm in diameter. This surface appeared as a dark tone (smooth) to P-band radar, as did the adjacent lake surface.

To the north of the Pisgah lava flows, the railroad and asphalt-paved highway exhibited little change in tone from system to system. The single-track railroad (BB) gave a strong return on all images, whereas the highway return was generally lower. Highway CC was probably defined on the imagery because of the gravel shoulders which formed elevated banks fringing the road, one of which would be inclined toward the transmitter. As expected, the imagery exhibited little or no return from the specular reflecting surface of the asphalt highway. However, the regraded, gravel-covered surface of the now-abandoned highway (AA) may have been penetrated, and some contribution to the P-band return signal may have been from the coarse fragmental materials underlying the surface and composing the foundation of the abandoned highway. Some contribution may also be related to the geometry of the road surface and shoulders, although geometry and orientation relative to look direction vary little with those of the paved road. The area through which this road passes consists of mixed fine- and coarse-grained alluvial material which contains scattered greasewood and creosote bushes. The relatively low return from this area is not an unreasonable contrast with the high return from the compact, coarse-grained mass which forms the foundations for the now-abandoned highway. A similar return from a secondary road (DD) adjacent to the railroad (CC) is also believed to be related to the subsurface structure of the roadbed.

TABLE 1 — TABULATION OF IMAGERY CHARACTERISTICS

Feature	Character of Return Signal on:			
	AN/APQ-97 K-band	AN/APQ-55 K-band	NRL C-band	NRL P-band
AA Unpaved road, 6.1 m wide, graded gravel with small patches of asphalt on old highway base. Gravel up to 2.5 cm diameter.	Defined by higher return only where crossing alluvial area of very low return. Poor definition looking south (HH and HV), almost imperceptible looking north.	Defined by higher intensity return than adjacent areas. Definition of degree similar to paved highway.	Moderately well defined, medium high return on HH image. Barely perceptible on HV on outer edge (far range) of image.	Strong -- comparable to and not distinguishable from railroad.
BB Single-track railroad	Strong	Strong	Strong	Strong
CC Paved road 9.8 m wide with 1.5 m gravel shoulders. Road surface of gravel up to 0.6 cm dia. in asphalt binder.	Faintly perceptible on south look HH image road orientation is normal to look direction. Barely perceptible in HV image. Barely perceptible on north look image (road normal to look direction), HH or HV. Contrast enhanced on south look image by shadowing and lower return from adjacent alluvium rocks.	At near range, parallel to flight direction, of medium intensity, but less so than railroad with same orientation.	Moderate return in contrast with low return alluvium, no contrast with lava field.	Not perceptible in areas of alluvium or lava.
DD Access road north side of railroad, single lane, graded gravel.	Absent	Absent	Absent	Narrow well defined line of strong return.

E NW extension of lava field. Lavas of 3 stages partly covered with windblown sand and silt up to 1.8 m deep in isolated depressions in lava surface.	No discrimination between lavas. Low return from areas covered with windblown debris with some isolated patches of high return where bare lava is exposed.	Not visible	Separation of 2 younger flows, pahoehoe and aa, with strongest return on VH image. Discrimination not evident on HH image. Return from partially silt covered lava higher and spottier than from alluvium.	No discrimination between lava types. No discrimination between lavas covered with windblown silt and sand and bare lava. Return signal primarily from buried lava surface.
G Windblown sand and silt covered lava west of Pisgah Crater.	Return signal is primarily from sediment cover. Lava margin not perceptible on imagery.	Not visible	Not visible	Return primarily from lava. High intensity return contrasts strong with lower return of adjacent sediment. Margin clear.
H, J J - 3rd phase Aa lava. H - 1st phase lava to NE, 2nd phase (pahoehoe) to SW.	No discrimination, strong return from both.	No discrimination, strong return from both.	Uniform return of moderate intensity from J. Moderate to low return from H, not so uniform as return from J.	Enhancement of edge of flow at contact between Aa (3rd phase and pahoehoe; 2nd phase) on north side of flows. Function of aspect angle.
K-L Vegetated area on dry lake with sage around which has accumulated windblown debris forming mounds up to 0.5m high and 2.4m diameter. Area contrasts strongly with flat mud-cracked surface of remainder of lake.	Intensity of return varies with density of vegetation. Return is high compared with general lake surface. HV return is less than corresponding HH return.	Not visible.	Return intensity strong in both areas comparing favorably with return from adjacent 1st phase flows.	SW look HH return intensity similar to lava but less intense. NE look return strong (slightly less than from lava) but only from K. Return from L is almost without contrast with K. HV return fails to define either area.

M-N M - mixed volcanics up to 25 cm dia. on wavey, undulating surface. N - fragments up to 5.1 cm dia., 80% less than 2.5cm. Area interlaced with channels of fine sand and clay. Overall relief less than 30 cm.	Uniform moderately intense return from M. Less intense and also uniform from N. Contrast accentuated in HV return.	Not visible.	Not visible.	Not visible.
P Alluvial fan on Sunshine flow. 85% fragments less than 5.1cm diameter, 75% less than 2.5 cm diameter. Predominantly subangular. Local relief less than 10 cm. Fragments on adjacent lava up to 60 cm diameter.	High intensity return with texture and intensity similar to adjacent Sunshine flow; fan not discernable in HH image. Higher return from fan in HV image; fan well defined.	Fan not defined; no contrast with adjacent lavas. Good contrast with low return of lake.	Fan not in contrast with adjacent lavas. Good contrast with low return of lake.	Fan gives same low return as does lake. Contrasts with high return of lava. Alluvial channel extending from fan to southwest source is also marked by low return. Sub-fan lava-lake contact clear.
Q Distributary channels of coarse debris on lakebed.	High return in contrast with lake sediments.	Contrasts strongly with low return from lake. Intensity only slightly greater than that of lava but more uniform in tone throughout.	Only isolated patches with return greater than that from lake.	Only a few isolated patches of high return in contrast with low return from lake.

Areas E and G also offer substantiating evidence to the penetrating capability of longer-wavelength radars. In both areas the irregularity of the lava surface, to some degree, has been compensated for by the filling of the low areas with windblown silts and sands derived from the alluvium in the northwest. The return signal on K-band radars reflects this state; the signal in part is from exposed lava and in part is from the intervening debris-covered areas. The signature of this area on P-band imagery, however, is dominated by the signal from the lava surface and there is not any indication of the partial cover of aeolian debris. Apparently, penetration of as much as 1.8m of dry windblown sediments in the centers of the depressions has occurred.

In this same region, whereas K-band radar is incapable of discriminating between flows of the various stages, C- and P-band imageries effect a separation between lavas of two phases, a separation that appears to be dependent on surface configuration (relative surface roughness). Differences in gray tone are minor, however, and edge enhancement to some degree appears to be responsible for the separation, although textural variations show some contrast along the contact (H-J).

One large area (K) on the east side of Lavic Lake is dominated by mounds up to 2.4 m in diameter and 0.5 m high, in the center of which is found a creosote or greasewood shrub 45-60 cm in height. The mounds average less than 0.3 m in height and 1.2 m in diameter. The images of the AN/APQ-97 radar well express the density of the brush, by isolated spots, clusters of points, or areas of high return isolated in an overall area of low return. The signature of this area on C-band radar, however, is analogous to that of the lava field; and the entire area through which the mounds are scattered appears as an integral unit of high return, in contrast with the adjacent low-return area of the lake. It is postulated that superimposed on the contribution to the return signal due to surface roughness and vegetation is a subsurface contribution, possibly related to the root system of the creosote and greasewood. Similarly strong contrasts of the vegetated area as a whole with the lake appear on the P-band image, although the return is not so strong as on C-band imagery. This may be the result of attenuation (loss of signal) through penetration or the decreased effect of vegetation and surface roughness. Area L, the return from which is similar to that from area K on K-band and C-band radar, stands out strongly in the south look image but is not unique in its signature on the north look images. On one cross-polarized return (HV*, P-band imagery), neither area gives a return higher than that from the surrounding lakebed.

Although the comparison of NASA and NRL imagery represents comparison of two systems with strong contrasts in dynamic range as well as resolution, apparently neither of these factors has been of prime importance in the enhancement of areas K and L on the NRL imagery. Maximum contrast in gray tones on AN/APQ-97 imagery is between Lavic Lake and the adjacent Pisgah flows, with a lesser degree of contrast between the general lake surface and the sparsely vegetated area in the lake. With compression of the dynamic range (as in the NRL system) one would expect this relationship to be accentuated, whereas the reverse is true. Inasmuch as longer-wavelength systems should be expected to "smooth out" such areas which appear rough to K-band radar, it must be concluded that penetration of the surface, in the vicinity of the plant community where subsurface soil moisture should be greater than in the barren areas of the lake, may be responsible for the accentuation of the return on longer-wavelength imagery.

An excellent demonstration of the relationship between wavelength, surface roughness, and intensity of return is to be found on the eastern side of Sunshine flow, where an alluvial fan has developed with the dumping of debris carried from the high surface of the flow to the southwest, across the eastern part of the flow and onto the lake. Spread out in fan shape across the essentially flat lake surface is water-transported fragmental material, predominantly lava, 85% of which is less than 5.1 cm in diameter and 75% of which is less than 2.5 cm in diameter. The configuration of this fan is well displayed on K-band imagery, and although

---

*HV: Transmit horizontal polarization, receive vertical polarization it contrasts only to a minimum degree with the adjacent Sunshine flow on like-polarized return, it contrasts strongly as an area of higher return on the cross-polarized imagery. The fan also contrasts with the lake bed on C-band imagery, but on P-band imagery the return from the fan is of essentially the same intensity as from the lake bed: the fan is thus not detectable on P-band imagery. Similarly, the distributary channels of coarse material spread out onto Lavic Lake at Q (not visible on the 1954 photography), are in strong contrast with the lake bed on K-band imagery, but show a decrease in contrast of intensity of return with the adjacent lake sediments on imagery of longer wavelengths. Thus, as would be expected, surfaces that might appear rough to K-band radar may appear smooth to longer-wavelength systems.

CONCLUSIONS

In spite of the drawbacks of comparison of imagery acquired at different time periods from different systems, sufficient conclusions can be drawn from a variety of K-, C-, and P-band images of the Pisgah Crater area to justify additional multiband radar imaging over this or other geologic test sites. Although sufficient data for a thorough evaluation of polarization, resolution, aspect angle, etc. are not available, evaluation of existing imagery has demonstrated that the radar return signal from certain cultural and natural phenomena is strongly wavelength-dependent. Surface roughness appears to be the parameter most strongly influencing radar return, but the penetrative capability of long-wavelength radar has under some conditions been a significant factor in determining the magnitude of the return signal. The real value of long-wavelength radar, judging from the evaluation of only a limited amount of imagery, is not its penetrative capability or any other single factor per se., but its unique total response to terrain characteristics, as compared to a shorter-wavelength radar system. Maximum value will be derived only when multiband imagery is recorded.

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