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SECTION 36

SURFACE CONFIGURATION AS AN EXPLANATION FOR LITHOLOGY-RELATED CROSS-POLARIZED RADAR IMAGE ANOMALIES

by

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INTRODUCTION

With the development of multipolarized side-looking radar systems, it became possible to record two orthogonal components of the backscattered radiation in the form of two congruent and simultaneously produced radar images, a like-polarized image, either HH or VV and corresponding cross-polarized image, HV or VH. Study of Westinghouse AN/APQ-97 Ka-band multipolarized imagery acquired in 1965 and 1966 as part of the Earth Resources Program has uncovered various targets that appear differently on the like- and cross-polarized images. One group of polarization anomalies has concerned geologists for some time, namely the significantly lower cross-polarized returns produced by certain volcanic rocks.

An explanation of these lower cross-polarized returns is the subject of the present investigation conducted at the Remote Sensing Laboratory of the Center for Research, Inc. at the University of Kansas with funding by NASA Contract NAS 9-10261.

The first geologic evaluation of simultaneously produced like- and cross-polarized images was performed by Dellwig and Moore (1966) in the Pisgah Crater area of Southern California. The area is a NASA test site and was imaged in 1965 with the AN/APQ-97 SLAR system using its full polarization capacity together with several look directions. Geologically, the area is composed of two Quaternary basalt flows, a playa, and large areas of alluvial fans. Studies of the imagery revealed that whereas the flows associated with Pisgah Crater and the areas of alluvium retained much the same appearance on all images regardless of polarization, the other basalt flow (Sunshine flow) produced images that were distinctly darker on cross-polarized returns than on like-polarized returns. This reversal in tone by the Sunshine flow allowed the easy discrimination of adjacent rock types on cross-polarized images that were difficult to separate on the like-polarized image. These and other polarization-related differences lead the authors to state that "In simultaneously produced like- and cross-polarized imagery, as exemplified by the Pisgah Crater area, the geologist finds information previously unattainable from only like-polarized radar imagery," (Dellwig and Moore, 1966, p. 3601).

About the same time, Cooper (1966), conducting a preliminary evaluation of K-band imagery in the Twin Buttes area of Arizona, (see Figure 2A), noted two areas of low return on the HV image that were not delineated on the corresponding HH image or aerial photographs. Subsequent field investigation established these areas as being previously unmapped outcrops of pyroxene rhyodacite. Noting no important differences in surface roughness between the outcrop and surrounding areas, Cooper suggested the high glass content of the rhyodacite as a possible cause for the differing radar returns.

Gillerman (1967) tested the preliminary hypothesis of Cooper concerning glass content by searching the K-band imagery of the Western United States for areas with lower return (darker) on the cross-polarized image than on the like-polarized image. A number of such areas were uncovered. All consisted of Tertiary or Quaternary volcanic rocks with wide ranging compositions and glass contents. This lead Gillerman to conclude that glass content was not the determining factor in producing lower returns on the cross-polarized imagery.

PROCEDURE

When the present study was undertaken, certain generalizations could be made concerning the nature of the anomalous returns.

1. These anomalies always produced bright like-polarized and dark cross-polarized images.
2. In test sites where the full polarization capability was used; the lower cross-polarized returns occurred independently of the polarization of the transmitted signal, that is darker VH images were produced as well as darker HV images.
3. In these same sites, lower cross-polarized returns appeared independently of look-direction.
4. The lower cross-polarized returns were apparently associated with volcanic rocks although they occurred independently of composition and glass content since both factors vary widely in the rocks producing such returns.

A further search of available multipolarized radar was conducted to uncover additional polarization anomalies. These were documented with respect to rock-type using published literature and maps. Aerial photos of many of these areas were obtained and studied, and finally, several areas were investigated in the field where samples were collected and ground truth was obtained. No single hypothesis was tested, many lithologic properties were considered in hopes of uncovering consistencies which may be responsible for the lower cross-polarized returns.

RESULTS

Search of the radar uncovered a number of cross-polarized anomalies which were not associated with volcanic rocks but were apparently caused by outcrops of certain sandstone formations, namely, the Navajo Sandstone of Utah and its time equivalent in southern Nevada, the Aztec Sandstone. Extensive outcrops of thick Tertiary clastics in the Imperial Valley of California also produced images with distinctly lower cross-polarized returns.

Gross lithologic differences between sandstones and volcanic rocks discounted many early hypotheses concerning various volcanic phenomena. Field investigation, however, has led to the conclusion that surface configuration of the outcrops involved is responsible for their appearance on multipolarized imagery. The manner in which these anomalous returns are produced is by specular non-depolarized reflection from planar rock surfaces.

In general, the rocks producing anomalous cross-polarized returns can be grouped into three general types: (1) certain geologically recent lava flows (late Pleistocene and Holocene), (2) some Tertiary volcanics and (3) certain massive sandstones. These three rock types, for differing reasons, produce terrains in which radar return is dominated by specular reflection from planar surfaces.

For a specular reflector to be recorded on a SLAR image, its orientation must be normal to the path of the impinging radar, and for such an orientation, Fung (1965) has shown that the depolarized component of the reflected radar energy is at a minimum. This results in a higher return onthe like-polarized image and a lower return on the cross-polarized image; which is in compliance with the observed multi-polarized behavior of the three rock types. When planar surfaces are normal to the path of the incident radar, both horizontally and vertically polarized radar behave the same since both are oscillating in the plane of the reflecting surface. This explains the fact that lower cross-polarized returns occur independently of the original polarization direction.

The planar rock surfaces are large with respect to the wavelength of the Ka-band AN/APQ-97 system (0.86 cm.) yet are small in comparison to the resolution. The outcrops involved represent highly faceted surfaces with facets of varying orientations. However only those of the proper orientation produce significant returns. Because there may be many facets so oriented in any given resolution cell, the observed radar images are averaged returns showing the dominance of specular reflectors in the production of the returns. In addition, the omnidirectional attitude of the facets and their wide distribution on the outcrops studied explains the independence of look-direction that the flat lying anomalous outcrops exhibit in production of darker cross-polarized images.

DISCUSSION

The first group of rocks, the young lavas, all have one characteristic in common — blockiness. This blockiness results from the actual eruption of the lavas. With dacites and rhyolites, the low temperature and high viscosity of the lava results in domes and thick stubby flows with surfaces littered by large blocks that yielded to the stresses of eruption. The rhyolitic domes and flows of the Mono Craters in east-central California are good examples. Some basaltic eruptions result in blocky flows because of rapid cooling of the lava while still in motion. The youthful lava associated with S. P. Crater in the San Francisco volcanic field of Arizona is a very blocky basalt that produces anomalous returns on multipolarized imagery. In both bases, the terrain is dominated by blocky fragments with planar surfaces that are much larger than the wavelength of the radar. Because of the youthfulness of the lavas, the effects of weathering are not much in evidence; soils and regolith are lacking and vegetation is minimal. Because of the large size of these flows as well as their well-defined boundaries, they are easily resolved on K-band imagery.

Figure 1a is a radar image of the Mono Craters recorded with an easterly look-direction. The top image is a like-polarized image (VV) whereas the lower image is cross-polarized (VH). Numerous parts of the north-south chain of extinct volcanoes appear darker on the cross image. These areas are all blocky domes and flows of recent geologic age composed of obsidean and punice of rhyolitic composition.

Figure 1b is a view of the small flow at the northern end (right) of the chain, which shows a sharply lower return on the cross-polarized image. The picture was taken on the younger flow looking in a northwesterly direction. Large angular blocks of punice are evident in the foreground. In the middle distance, an older flow can be seen which has been buried by an intervening episode of ash erruption. As a result, the blocky nature of the older flow is concealed and vegetation is developed which together with the puffy ash covering produces a diffuse and depolarized return.

Figure 1c is a close-up view of the angular blocks of pumice which make up the surface of the flow. The smoothness of these surfaces is apparent. In addition the vesicles of the pumice are small and evenly distributed. Thus there are no discontinuities in the blocks to produce internal reflecting boundaries. As a result most of the return from these blocks is produced by reflection from the surface, which in this case is specular. In other areas, particularly in the flows to the south, obsidian makes up the blocks which dominate the surfaces. For the same reason as in the case of pumice, similar low cross-polarized returns are produced.

The second group of rocks are also volcanic including some shallow intrusives but are older, generally tertiary in age and thus have undergone more extensive weathering. The cause for differential depolarization by this class of rocks is again blockiness. In this case, however, the blockiness is due to weathering which produces blocky outcrops and extensive areas of rubble. However, because of the age of the outcrops, soils and vegetation have also developed. Thus it is only in dry climates such as in the southwestern part of the country that soil development and vegetation cover is suppressed sufficiently to permit the blocky rubble to contribute significantly to the radar return. Because the radar return from these rocks is only partially due to specular reflection, the differences between the like- and cross-polarized returns are usually less than those observed with the first class of rocks.

Figure 2a shows HH and HV images of the Twin Buttes area. Arrows indicate the outcrops of pyroxene rhyodacite studied by Cooper. Figure 2b is a view of the large northern outcrop. The difference in vegetation is largely due to the blocky surface which hinders root development of larger plants such as the mesquite trees in the foreground. Figure 2c is a view of blocks of rhyodacite which protrudes above the sparse cover of short grasses.

The third rock type accountable for differential depolarization are the thick massive sandstones particularly those of a friable nature that are easily physically weathered. Such sandstones are swept clean with each rain, thus extensive bare rock outcrops are capable of forming. Because these sandstones weather into broad smoothly rounded forms, there are limited surfaces in a given area that have the proper attitude to reflect radar energy back to the receiver. This accounts for the speckled return these rocks produce on the like-polarized image with the bright specks representing surfaces of the proper orientation. The cross-polarized image is almost completely black. The Navajo Sandstone of the Colorado Plateau behaves in this manner as does its time equivalent in southern Nevada, the Aztec Sandstone.

Figure 3a is a radar image in southern Nevada to the north of Lake Mead. Numerous bright specks on the HH image appear completely dark on the HV image. These returns are produced by outcrops of the Aztec Sandstone such as pictured in figure 3b. Such outcrops are devoid of soil and vegetation and present extensive areas of bare sandstone surfaces which are quite smooth, as shown in figure 3c. As in the case of fine-grained volcanics, fine-grained massive sandstone presents a homogeneous medium to the incident radar, as a result, the returning signal is dominated by reflection from the surface which again is specular and maintains its original polarization.

The three rock types discussed are not the only ones capable of producing dark cross-polarized images, however they are the only ones thus far uncovered which do so on Ka-band imagery. Scale and resolution appear to be the limiting factor; since an ideal surface has to be of sufficiently uniform and sufficiently large in area to be delineated on small scale Ka-band imagery. With the employment of higher resolution multipolarized radar systems this type of radar return may become more important in the interpretation of radar imagery and may be found to be produced by additional rock types.

Non-depolarized reflection is dependent upon smooth surfaces, as a result the production of dark cross-polarized images by rock surfaces is frequency dependent. The interrelationships of frequency and polarization in the production of radar images of various natural surfaces is an area that needs further study. The possibility exists that the combination of a multipolarization capability with one or two different frequencies could provide the same amount of terrain information as the use of several frequencies with the same polarization configuration.

CONCLUDING REMARKS

Three rock types: (1) geologically recent blocky lavas, (2) some Tertiary volcanics and (3) certain massive sandstones produce radar images characterized by bright like-polarized returns and dark cross-polarized returns. Outcrops of the three rock types discussed share certain features; planar rock surfaces that are large in comparison with the wavelength of the incident radar are abundant and detrital material and vegetation are of secondary importance; the planar surfaces appear to significantly contribute to the returning radar energy with this energy maintaining a constant polarization; the outcrop areas are of sufficient size and sufficiently uniform character to be delineated on small scale K-band imagery. In addition, this mode of reflection may become of more importance inthe design and utilization of future radar systems.

REFERENCES

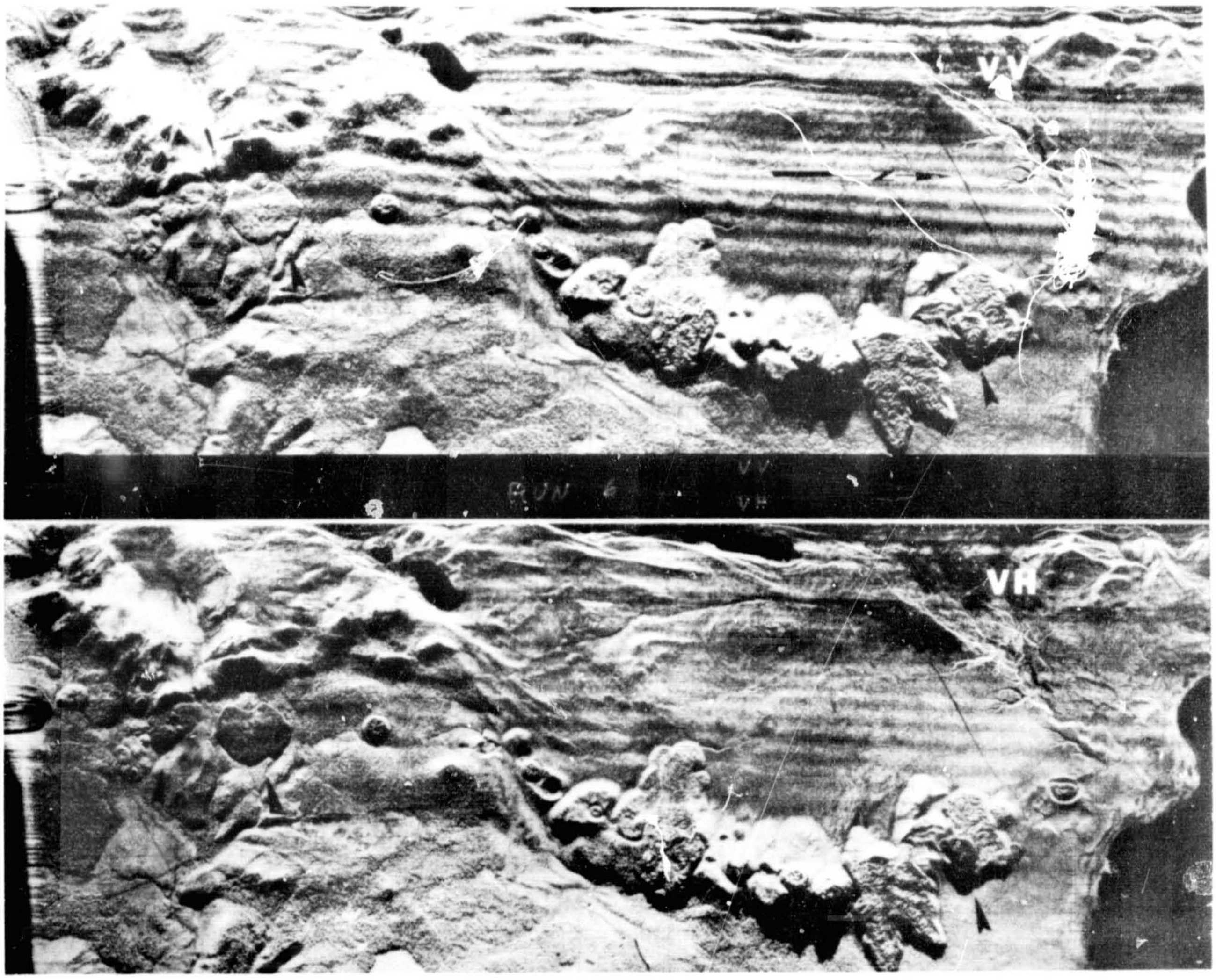
1. Dellwig, L. F. and R. K. Moore (1966) The Geological Value of Simultaneously Produced Like- and Cross-Polarized Radar Imagery: Journal of Geophysical Research, vol. 71, no. 14, pp. 3597-3601.

2. Cooper, J. R. (1966) Geologic Evaluation - Radar Imagery of Twin Buttes Area, Arizona: U. S. Geological Survey Unpublished Report.

3. Gillerman, E. (1967) Investigation of Cross-Polarized Radar on Volcanic Rocks: Kansas University Center for Research, Inc. (CRINC), Technical Report 61-25, 11 pp.

4. Fung, A. K. (1965) Scattering and Depolarization of Electromagnetic Waves by Rough Surfaces: Kansas University Center for Research, Inc. (CRINC), Technical Report 48-5, 22 pp.

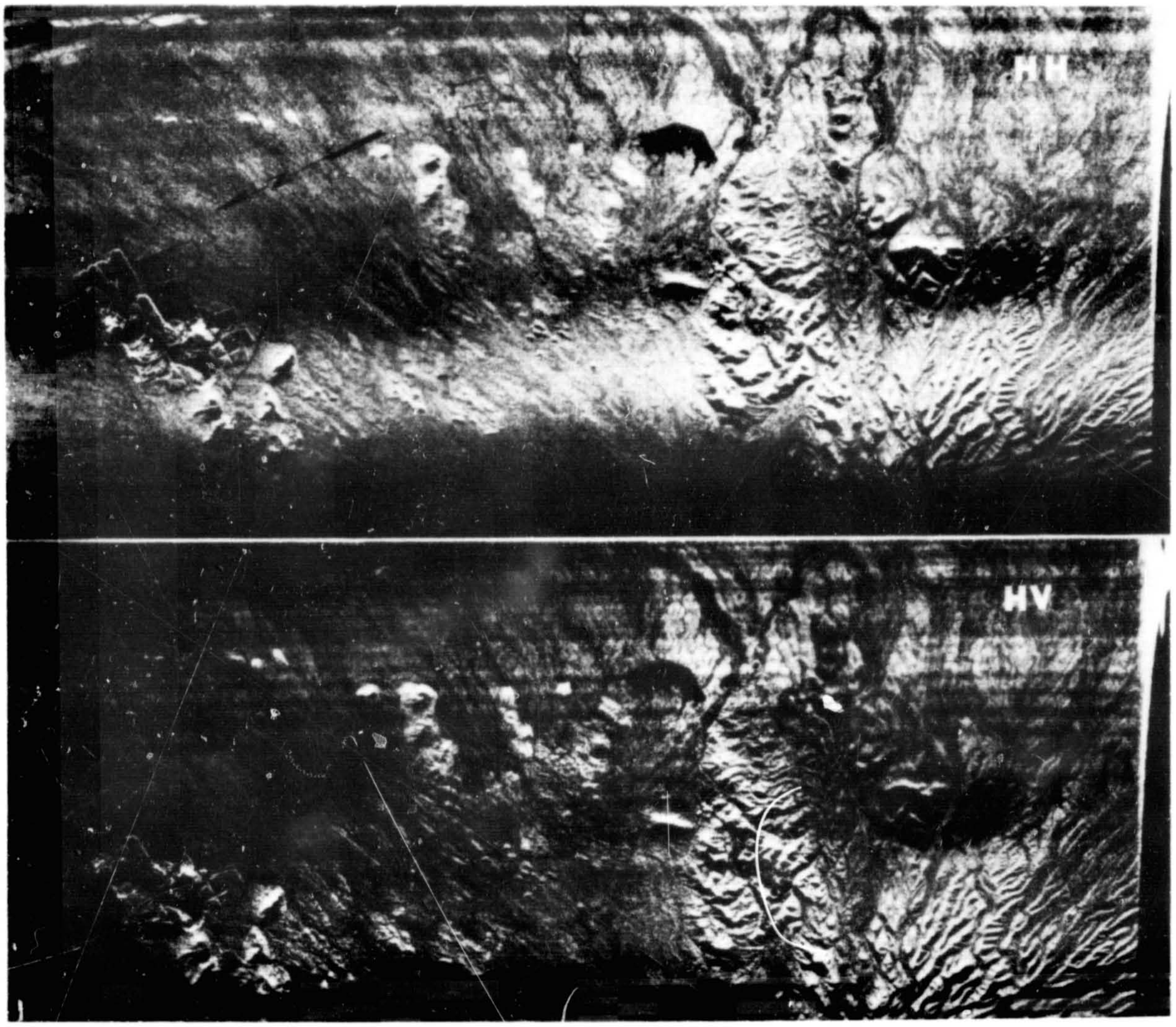
5. Moore, R. K. (1969) Radar Return from the Ground: University of Kansas Publication, Bulletin of Engineering No. 59, 87 pp.



1a VV and VH images of Mono Craters, showing tonal reversals associated with recent blocky flows.

1b View on northern-most anomalous flow looking northwest.

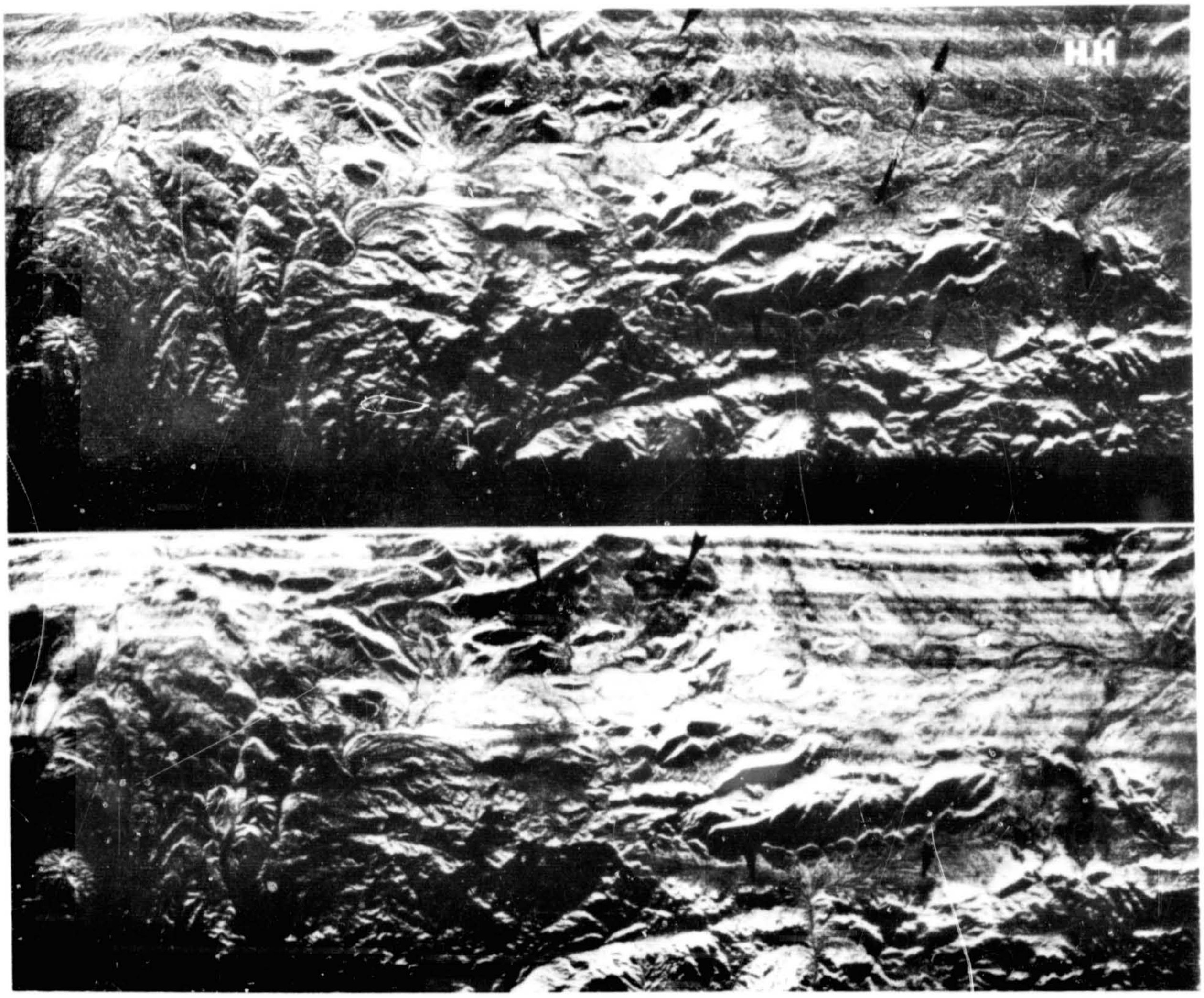
1c Close-up of pumice blocks.



2a HH and HV images of Twin Buttes mining district, Arizona showing anomalous returns from pyroxene rhyodacite.

2b Distant view of northern-most outcrop

2c Close-up showing blocks of pyroxene rhyodacite.



3a HH and HV images of southern Nevada showing numerous tonal reversals caused Aztec Sandstone.

3b Typical outcrop of Aztec Sandstone.

3c Close-up of surface of Aztec Sandstone.