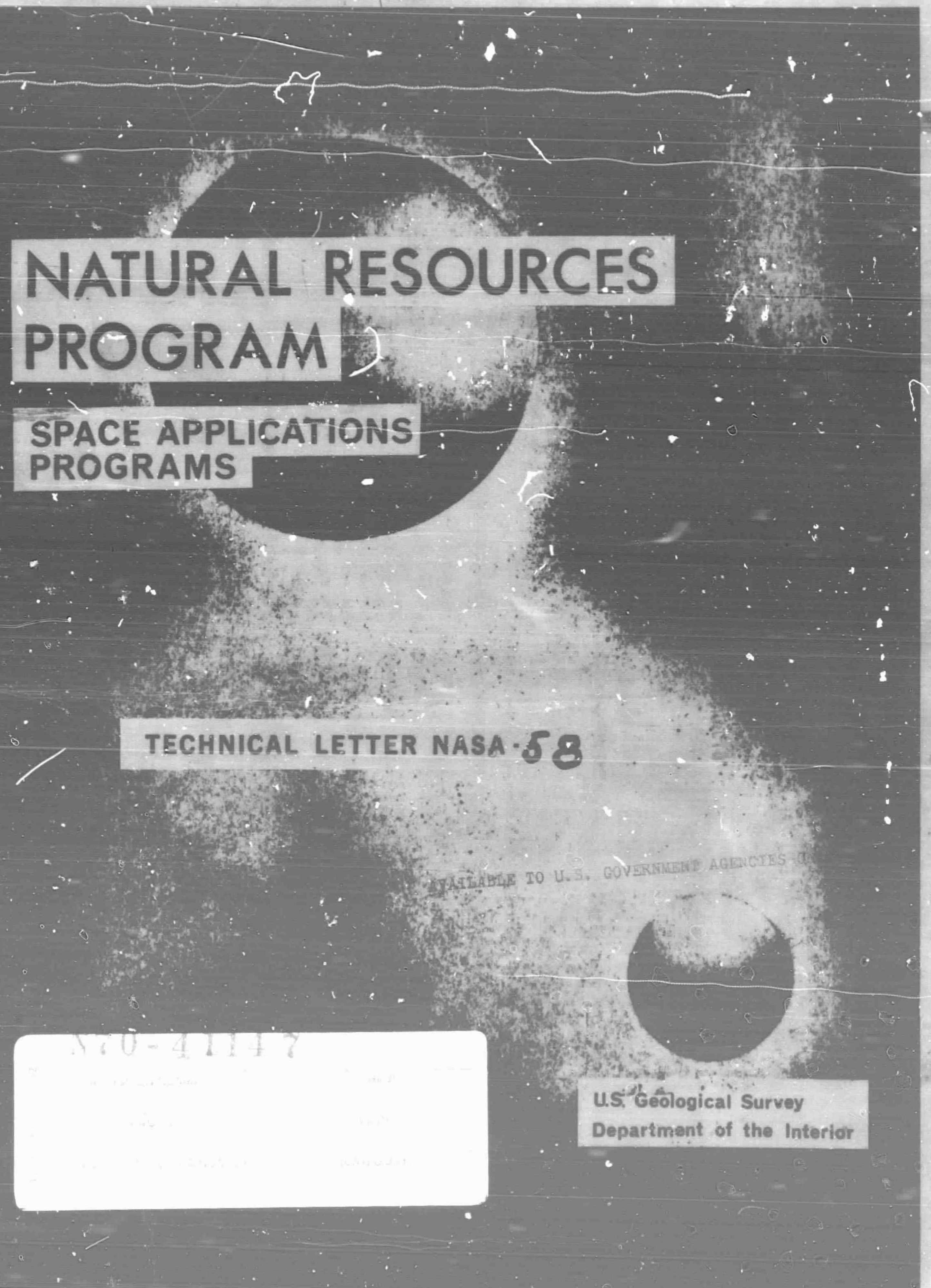


NATURAL RESOURCES PROGRAM

SPACE APPLICATIONS PROGRAMS

TECHNICAL LETTER NASA-58

U.S. Geological Survey
Department of the Interior

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON, D. C. 20242

Technical Letter
NASA-58
November 1966

Dr. Peter C. Badgley
Chief, Natural Resources Program
Office of Space Science and Applications
Code SAR, NASA Headquarters
Washington, D. C. 20546

Dear Peter:

Transmitted herewith are 3 copies of:

TECHNICAL LETTER NASA-58

GEOLOGIC EVALUATION OF RADAR IMAGERY IN SOUTHERN UTAH*

by

R. J. Hackman**

Sincerely yours,

William A. Fischer
Research Coordinator
Earth Orbiter Program

*Work performed under NASA Contract No. R-09-020-015
**U. S. Geological Survey, Washington, D. C.

[redacted]

UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

TECHNICAL LETTER NASA-58

GEOLOGIC EVALUATION OF RADAR IMAGERY IN SOUTHERN UTAH*

By

R. J. Hackman**

Prepared by the Geological Survey
for the National Aeronautics and
Space Administration (NASA)

*Work performed under NASA Contract No. R-09-020-015
**U.S. Geological Survey, Washington, D. C.

TABLE OF CONTENTS

Geologic Evaluation of Radar Imagery in Southern Utah

By

Robert J. Hackman

ABSTRACT

Radar imagery extending from the Dark Canyon Plateau to Table Cliff Plateau in San Juan and Garfield Counties, Utah was enlarged and compared with conventional aerial photography to determine what geologic features, if any, could be recognized on the radar imagery that were not present or were poorly defined on conventional photography.

Radar offers distinct advantages in having an all-weather, day or night capability of imaging large areas of terrain without the disadvantages of variable illumination angle found in mosaics of conventional photography. Side-looking radar produces a "shadow" enhancement effect that shows greater topographic detail, important to observation of many geologic features, than can be seen on a single aerial photograph taken with high-angle solar illumination. One fault was clearly visible on radar imagery that could only be poorly discerned on conventional photography. Calcareous and gypsiferous sedimentary rocks were shown as very light tones of gray in contrast to darker toned sandstones and shales. Fissile marine shales (dark tones)

could be distinguished from sandstone members (light medium tones) of the Mancos Shale and some calcareous beds (light tones) in the lower Mancos Shale and underlying Dakota Sandstone. These contrasts were less conspicuous on the conventional aerial photography of the area. On the other hand, many of the rock units, readily distinguishable on the photography, could not be positively differentiated on the radar imagery.

Geologic Evaluation of Radar Imagery in Southern Utah

By

Robert J. Hackman

INTRODUCTION

The radar imagery evaluated in this report covers a strip approximately 15 miles wide extending westward, 110 miles from Dark Canyon Plateau to Table Cliff Plateau in San Juan and Garfield Counties, Utah. (See figure 1). This imagery was taken October 4, 1965, at the request of the U. S. Geological Survey and the National Aeronautics and Space Administration (NASA). The imagery is the result of reflections obtained from scanning the ground with an airborn energy source in the K band of the electromagnetic spectrum.

The imagery is a continuous strip and has an approximate scale of 1/250,000. Both a positive print and transparency were used in this study. Parts of the strip were enlarged to an approximate scale of 1/60,000 to facilitate contrast with conventional high altitude vertical aerial photography (1/50,000 and 1/60,000 scale). The normal 1/250,000 radar strip is in duplicate in a 70 mm format. The upper one is the "like image" in which the signal is transmitted and received in the same plane. The lower one is the "orthagonal" or "unlike" image in which the signal is transmitted in one plane and received in the other (HV or VH).

General capabilities of radar imagery

Radar is an all weather, 24 hour a day, sensor for gathering geologic data. Unlike conventional aerial photography which generally relies on solar illumination and requires cloud free skies, radar uses its own energy source for scanning the terrain and has cloud penetration capabilities.

One of the most advantageous features of radar imagery is the over-all view it presents of large areas of terrain. Also, as the emitted radar energy is side-looking and does not pass through objects, it produces its own "no show" or "shadow effect" on the far side of topographic features away from the flight line, thus enhancing and presenting a three dimentional view of the terrain in a manner similar to a shaded relief map. The radar imagery is best viewed with shadows falling toward the viewer.

As the radar "shadows" result from low angle (to the horizontal) energy source, small irregularities in the topography of the surface enhanced by "shadows" can be seen on the imagery. These irregularities are readily seen on a radar image but are usually not recognized on a single conventiona, high angle illuminated, vertical aerial photograph. Pairs of photographs must be viewed stereoscopically to see many of these same features.

Most conventional aerial photography is taken under high angle solar illumination (between 10:00 AM and 2:00 PM). If it were taken early in the morning or late in the day, under low angle illumination it would show a similar shadow enhancement (Hackman, 1966). However, the direction of solar, low angle illumination and subsequent ahadows, are restricted by the earth's rotation around the sun and will generally be in a near easterly or westerly direction, depending on the time of day and the geographic location of the area of interest. Radar, in contrast, has no such limitation since it uses a self contained energy source, which can be flown in any direction.

In considering the tone values of various rock units represented on radar imagery, one has to consider the angle of "illumination" (energy source), for there is a highlight and shadow effect related to the angle at which the radar scan strikes an object. Slopes and faces of cliffs at right angles and facing the energy source reflect more incident energy than the same material flat lying or sloping in other directions. On radar imagery, values related to different rock types are generally best seen in areas of low relief where the highlight and shadow effect is less evident. Even in such areas the tone value for a certain rock type will vary some from place to place depending on the angle of "illumination" and the "surface roughness" or number of edges (corner reflectors) that are present.

Method of Study

Enlarged portions of radar imagery, at a scale of approximately 1/60,000, were compared with conventional 1/60,000 and 1/50,000 scale aerial photography to determine what geologic features could be recognized on the radar imagery that were not present or only poorly defined on the conventional photography. The comparison with the photography was a two-fold step. It was first compared to a single aerial photograph and then where necessary with the stereoscopic model of two overlapping photographs of the same area. The radar imagery and photography were further compared to the geologic map of the area, and significant geologic features found on the radar image were field checked in the summer of 1966. This field work was done in conjunction with field investigation for compilation of the Escalante (2 degree) Geologic Map by Donald G. Wyant and R. J. Hackman of the U. S. Geological Survey. They were joined by Paul Williams and William Bower while investigating the Table Cliff Plateau area.

Geology and Ecology

Rocks in the area range in age from Paleozoic to Tertiary and include extrusive and intrusive igneous rocks and sedimentary rocks. All in part are covered by Quaternary surficial material. Major structural features from east to west are: part of the west flank of the Monument Upwarp, southern part of the Henry Mountains

Basin, including the Mt. Holmes and Mt. Elsworth intrusive structures, the east-dipping Waterpocket Monocline, the northern end of the Circle Cliffs Upwarp, the west-dipping Escalante Monocline and the Table Cliff Syncline which is a northern extent of the Kaiparowits Downwarp.

The western part of the area, west of Escalante, is mostly tree covered. In descending order from the top of Table Cliff Plateau are found the Spruce-fir zone (9,000 to 10,000 feet), the Ponderosa pine-Douglas fir zone (6,200 to 9,500 feet) and the Pinyon-juniper zone (5,000 to 8,500 feet). East of Escalante, pinyon and juniper are found on the flanks of the Circle Cliffs Upwarp, Mt. Holmes and Elsworth and the higher elevations of Dark Canyon Plateau. The remainder of the area is sparsely covered with a northern desert flora including sagebrush, blackbrush, Morman tea, shadscale, and some short grasses (Cannon, 1960).

Horizontal and vertical polarized radar imagery

The vertical and horizontal polarized imagery at a scale of approximately 1/250,000 (transparency strip) were simultaneously viewed by means of a binocular stereoscope with adjustable wing mirrors. No significant differences were observed between the two that were thought to have geologic significance.

Geologic structure on radar imagery

Evaluation of radar imagery in this area shows that many geologic structures are clearly defined on the imagery. This is undoubtedly due to the radar "shadow" enhancement of topographic expressions of these structures. However, in the area covered by this study, most of these geologic structures are clearly visible on the ground and can also be interpreted in the stereoscopic model of two aerial photographs, with a greater precision. Because of the "shadow" enhancement and the greater area coverage of the radar imagery, it certainly shows more geologic structure at a casual glance that can be seen on a single aerial photograph or photo mosaic of the area. One additional geologic structure could be seen on the radar imagery that was only partly visible on conventional aerial photography.

Alignment of concealed fault or faults - - The alignment of a concealed fault or faults under a thin layer of surfical material (alluvium and windblown sand) shows up on a radar image of a part of the Circle Cliffs area. This fault or faults is very poorly expressed on 1/50,000 scale conventional photography (including stereoscopic viewing) where it crosses the canyon floor. (See figure 2).

The fault or faults cross the Right Hand Fork of Silver Falls Canyon, one mile east of the northern end of Big Brown Mesa. The geologic map of the area (Carswell, et al, 1958) shows an approximately located and partly concealed fault crossing the canyon floor. The downthrown side of the fault is to the north. The radar imagery shows a lineation just to the north of the field mapped fault. This may be the main fault or a branch of the fault, not previously recognized in the field, and which dies out to the west before it reaches the canyon wall. The topographic expression of the canyon wall, just north of the field-mapped fault, suggests this possibility.

It was not determined in the field what causes the distinctive tonal break across the fault or faults. The dark tone in the immediate vicinity of the fault may be due to moisture along the fault zone and in the alluvium. The overall dark tone to the south could be due either to greater moisture content or a difference in reflectivity and, probably, lithology of rocks of the Moenkopi Formation on either side of the fault.

Differentiation of rock units on radar imagery

The differentiation of rock types on radar imagery is in general much more difficult than on conventional photography; although some surficial deposits are better displayed on radar imagery than on a single aerial photograph. However, in stereoscopic models of conventional photography such material can usually be delineated more easily. The radar imagery is however, definitely superior to conventional photography (on both the single photograph and in the stereoscopic model), in differentiating rock units in two specific cases in the area of study. They are discussed in the following paragraphs:

Greater tone discrimination between Navajo Sandstone and Carmel Formation on radar imagery - - Radar imagery shows a greater tone discrimination between the Navajo Sandstone of Triassic and Jurassic age and the Carmel Formation of Jurassic age than is apparent on conventional photography (figure 3). Not only is the contrast greater on the radar imagery by a factor of two, but it is a reverse contrast. The radar imagery shows the Navajo Sandstone to be darker in tone value than the Carmel Formation while the aerial photograph shows the Carmel to be darker than the Navajo but of less contrast.

The Navajo Sandstone in this area is a massive, white, cross-bedded sandstone of eolian origin approximately 1200 feet think. The reddish colored Carmel Formation, on the other hand, is 200 feet thick in this area (Gregory, 1931), and is predominately gypsiferous with considerable calcareous material and subordinate amounts of sandstone and shale. A massive gypsum bed 45 feet thick is in the lower part of the unit and 85 feet of gypsum and gypsiferous shale at the top of the unit. The gypsum and limey beds are most likely responsible for the high reflectivity of radar energy which shows on the imagery as a mottled white pattern. In contrast the white, rounded, forested, quartz, grains of Navajo Sandstone, although of lighter tone value on the aerial photograph, are a poorer reflector of radar energy and appear as darker in tone value on the imagery.

Some wind-blown sand is present on the Navajo Sandstone bedrock surface as indicated by the darker toned areas on the aerial photograph. The darkest specks on the photograph are pinyon and/or juniper trees. The radar imagery in the area shows no discrimination between the unconsolidated sand and the consolidated sand.

Calcareous material in Mancos Shale - - Twelve miles southwest of Mount Hillers (Henry Mountains area) the radar imagery shows a light tone band in the lower part of the Tununk Shale Member of the Mancos Shale which is not recognizable on the aerial photographs or stereoscopic models of the area. Field investigation of this area revealed the presence of thin limestone beds and calcareous shale at this horizon. It appears that this unit has much higher radar reflectivity than does the adjacent black (weathers blue-grey) fissile shale (figure 4).

CONCLUSIONS

Radar imagery should provide a useful tool for geologic interpretation both as a supplement to present conventional aerial photography and as an advantageous substitute in specific areas and for specific problems. The above statement is restricted to the interpretive use since the radar imagery used in these investigations does not have the geometric integrity required for making highly precise geologic maps.

Radar imagery has the following capabilities:

1. It shows an overall view of a large area of terrain, hitherto not obtainable on a single aerial photograph. When orbital photographs become generally available in the not too distant future they will, no doubt, more than compensate for this difference.

2. It has all weather capabilities. The surface of areas usually cloud covered can be recorded on radar imagery.

3. It shows greater topographic detail resulting from radar "shadow" enhancement than can be seen on a single conventional aerial photograph. This enhancement results from the low angle of radar "illumination" as contrasted to the high angle of illumination required for most conventional aerial photography.

4. There are no restrictions on the direction of "shadows" on radar imagery in contrast to low angle illuminated aerial photography

where the direction of shadows are controlled by the earth's rotation and the earth-sun relationshop. Radar imagery can be flown in any direction and at any time of the day since the direction of flight controls the direction of "shadow" enhancement.

Radar imagery depicts some faults that are not always recognizable on aerial photographs. This capacity may be due to a moisture difference on one side of the fault and/or to a difference of reflectivity related to the different rock units present on either side of the fault.

5. Radar imagery provides some definite rock signatures in this area of study. Calcareous and gypsifereous beds are shown as very light tones of grey in contrast to the darker toned sandstones and shales. The fissile marine shales of the Mancos Shale appear as dark tones in contrast to the medium-toned sandstone members of the Mancos Shale and some light toned calcareous beds in the Lower Mancos Shale. These contrasts in rock units are much less conspicuous on the conventional aerial photography of the area. On the other hand, many of the other rock unites that could be readily distinguished on the photography could not be positively differented on the radar imagery.

6. Quaternary alluvial deposits in some places are more discernable on the radar imagery than on a single aerial photograph.

7. Radar imagery does not appear to discriminate between surficial wind blown sand and sandstone.

REFERENCES

Cannon, Helen L., 1960, The Development of Botanical Methods of Prospecting for Uranium on the Colorado Plateau: U. S. Geol. Survey Bull. 1085-A, Plate 1 (in pocket)

Carswell, L. D., Davidson, E. S. and Miller, G. A., 1958, Preliminary Geologic Map of the Circle Cliffs 1 SW Quadrangle, Garfield County, Utah: U. S. Geol. Survey, Mineral Invest. Field Studies Map, MF-155

Davidson, E. S., Brew, David A. and Carswell, L. D., 1958, Preliminary Geologic Map of the Circle Cliffs 1 SE Quadrangle, Garfield County, Utah: Mineral Invest. Field Studies, Map MF-158

Hackman, R. J., 1966, Time, Shadows, Terrain and Photointerpretation: U. S. Geol. Survey, Technical Letter NASA-22

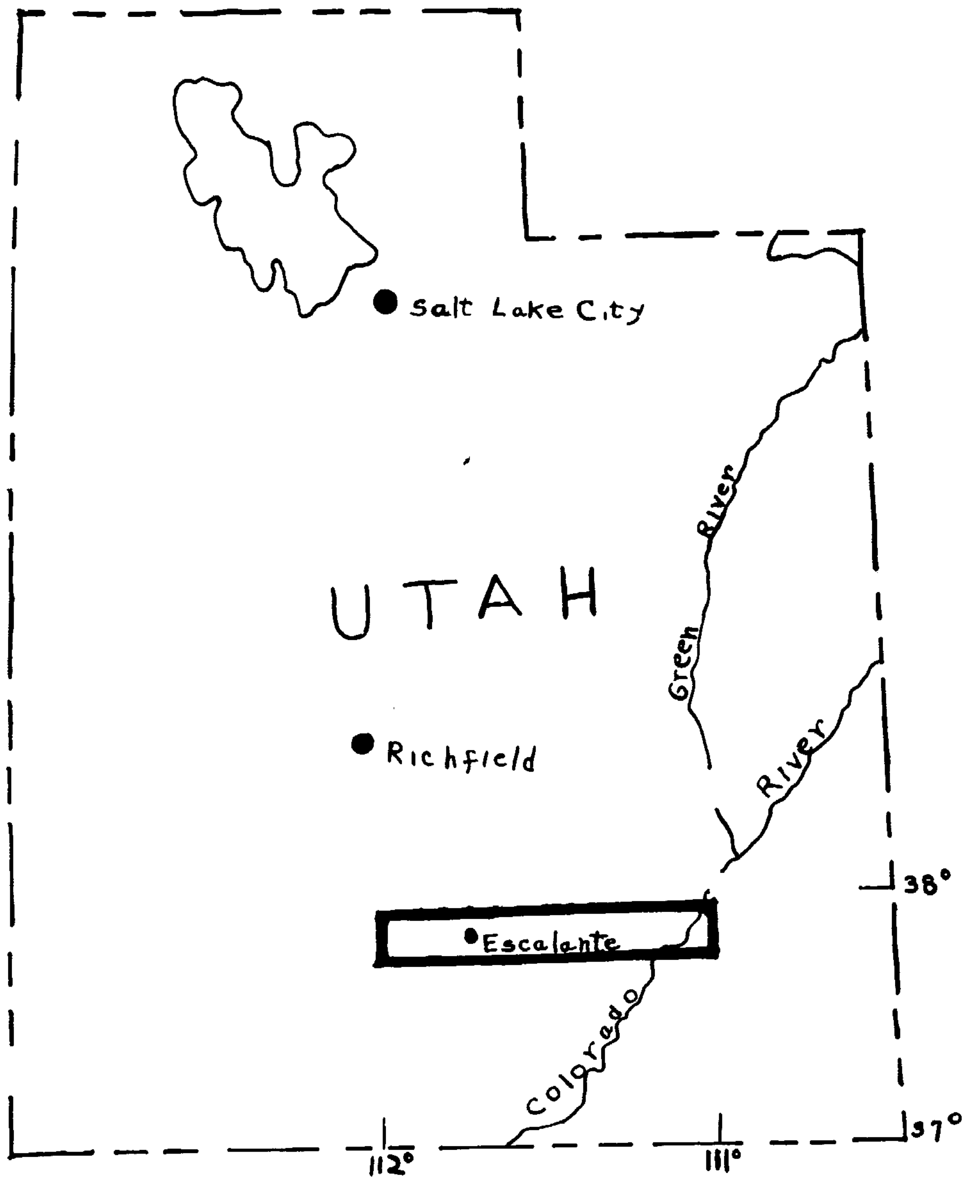


Figure 1. Index map showing area of radar imagery covered by this report.

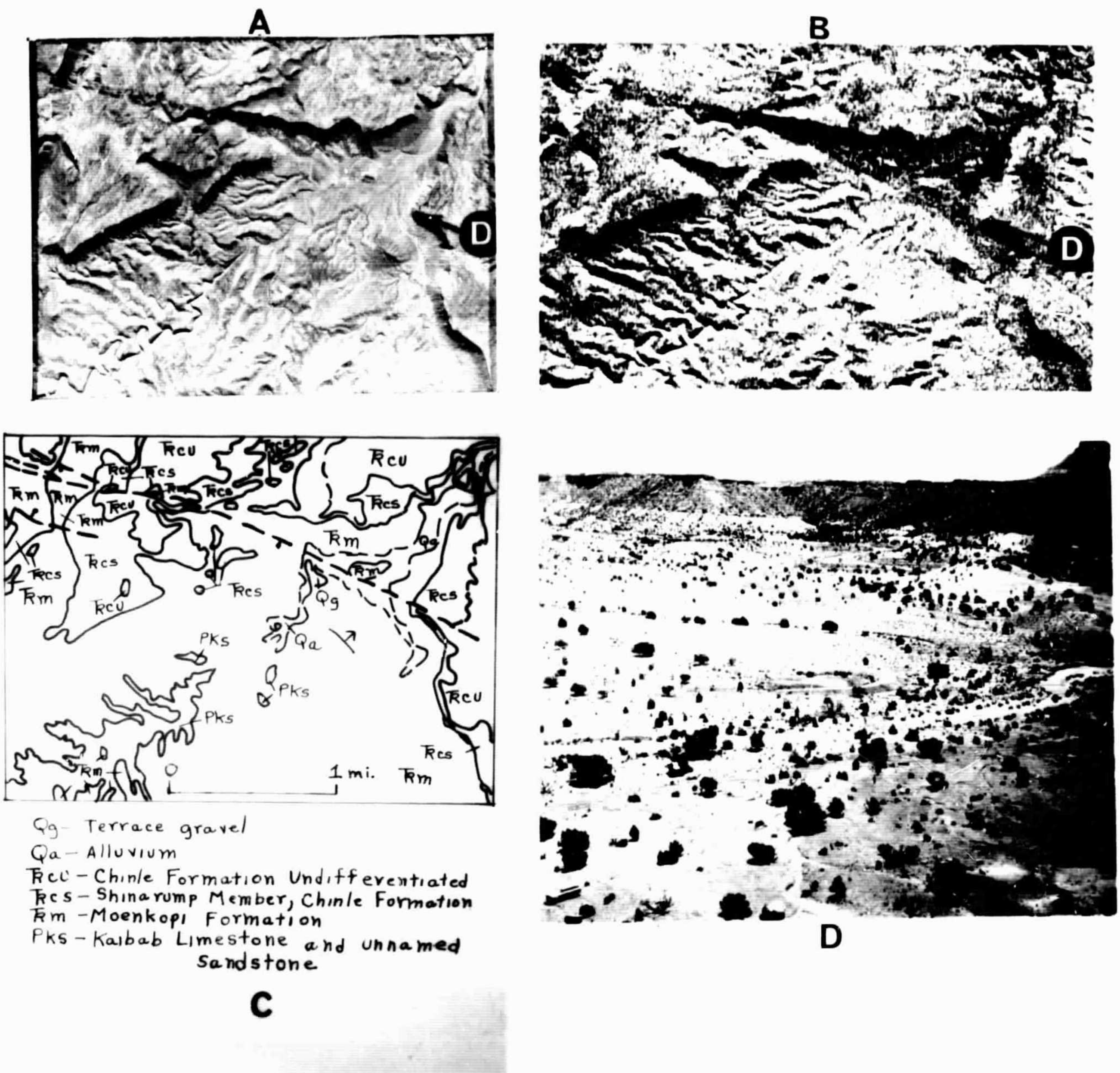
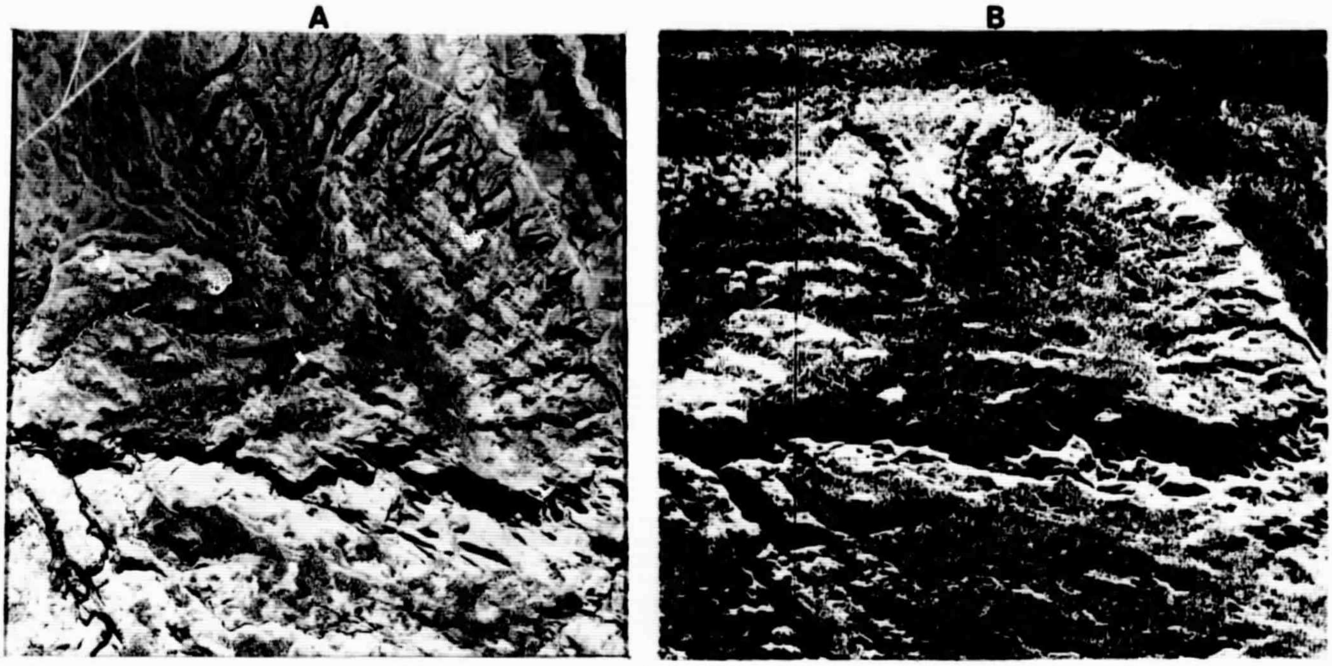


Figure 2. An aerial photograph, A; a radar image, B; a geologic map*, C; and a ground photograph, D; of an area in the Circle Cliffs area of southern Utah. The radar image shows a sharp tone change just north of the field mapped fault, where it crosses the canyon floor, suggesting that the fault may branch to the north of the field mapped fault. This tone change is not recognizable on the aerial photograph (including stereoscopic viewing) or on ground photograph. There is, however, on the aerial photograph a faint lineation about half way across the Canyon floor from the left. The position (point D) from which the ground photograph was taken is indicated on the radar imagery and the aerial photograph. The tone change is probably due to either an increase in moisture content south of the fault or faults or a reflectivity difference in units of the Moenkopi Formation exposed on either side of the fault or faults.

* Geologic map from Carswell, et al, 1958, and Davidson, et al, 1958.



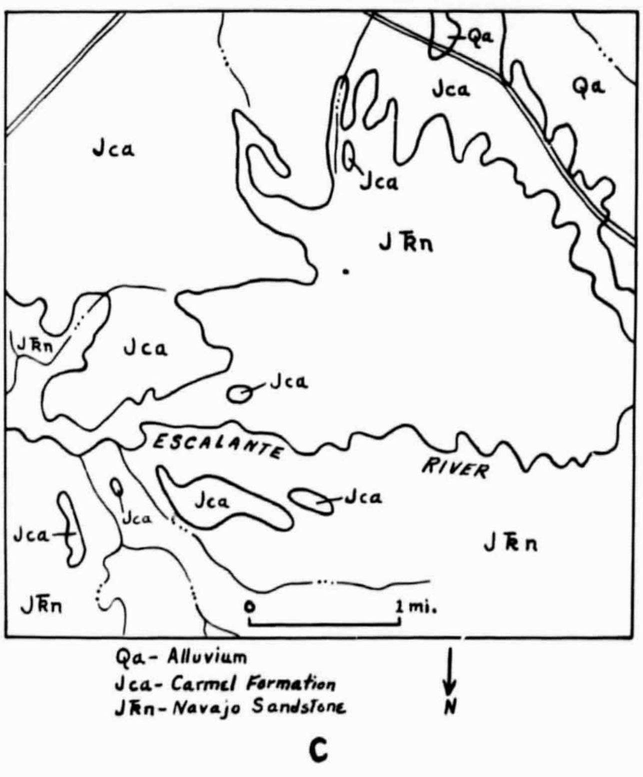


Figure 3. An aerial photograph, A; a radar image, B; and a geologic map*, C; of a few miles east of Escalante, Utah, where the younger Carmel Formation overlies the Navajo Sandstone. The greater contrast between the two formations is much more apparent on the radar imagery. Not only is the contrast greater but it is reversed from that on the aerial photograph. The mottled white color of the gypsiferous and limey material of the Carmel Formation seen on the radar imagery strongly suggests that this material is a better reflector of radar energy than the rounded quartz sand grains in the underlying formation. The radar imagery does not discriminate between the unconsolidated wind-blown sand (darker toned areas on Navajo Sandstone of aerial photograph) and the consolidated underlying sandstone. On the radar image the alluvium (top, right corner of image) and which includes some wind-blown material shows up in greater tone contrast with the Carmel Formation than on the aerial photograph.

* From Utah Geologic and Mineralogical Survey, Geologic Map of Southwestern Utah, 1963 and Southeastern Utah, 1964.

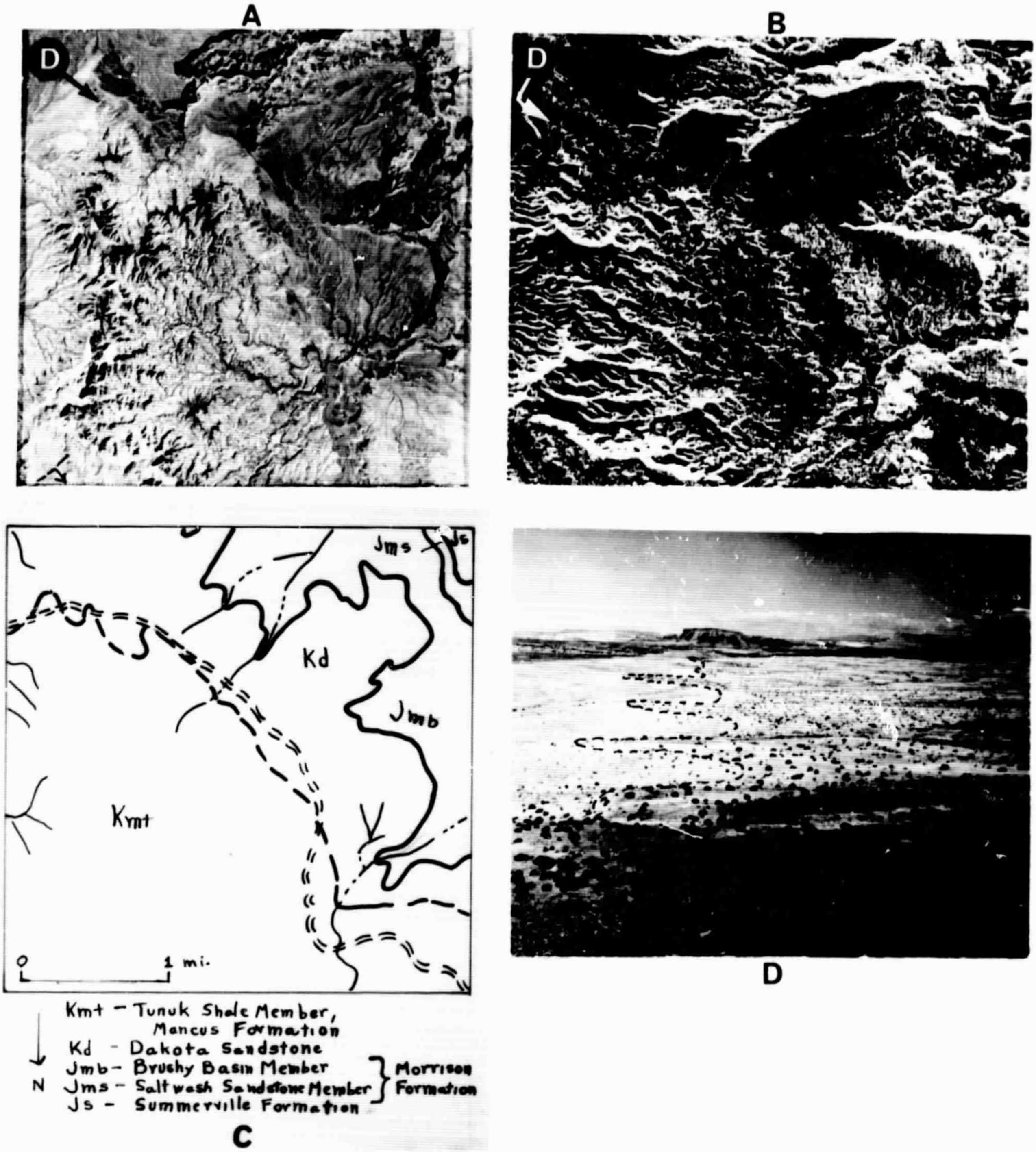


Figure 4. An aerial photograph, A; a radar image, B; a geologic map*, C; and a ground photograph, D; of an area twelve miles south of Mount Hillers in the Henry Mountains area. The arrow indicates location of and the direction the camera was pointing the ground photograph. Field investigations indicate that the light toned band visible on the radar imagery and only poorly expressed aerial photograph represents some calcareous material in the Tunuk Shale Member of the Mancos Shale. The adjacent dark material is black fissile shale which weathers blue-grey on the surface.

* From Plate 1, U.S.Geological Survey, Prof. Paper 228, Geology and Geography of Henry Mountains Region Utah, by C.B.Hunt, Paul Averitt and R.L.Miller.