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A RADAR ANALYSIS

by

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ABSTRACT

A comparison of structural data obtained from side looking radar (SLAR) imagery of the Grand Canyon area, northern Arizona with previously published reports demonstrates the potential of radar imagery as a tool for geologic reconnaissance studies. The study, designed to determine the geologic causes for a pronounced lineament pattern on the radar image, also provided a measure of reliability for the radar image interpretation, particularly the size of structure which may be interpreted with confidence.

The radar lineaments of the Grand Canyon area indicate the location of faults in the deformed Precambrian and relatively undeformed Paleozoic strata. The strong correspondence of radar lineaments with known faults is indisputable and to a lesser but still significant degree the joint pattern and the radar lineament pattern showed a close correlation. A number of lineaments on SLAR imagery in areas where no faults have been mapped substantiates the previous suggestion of SLAR as a geologic reconnaissance tool.

The length of a fault is an important factor in a radar image identification. In the study area, a fault of less than one mile in length is difficult to identify as a geologic structure, while the increasing length of a lineament lends creditability to a structural interpretation.

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INTRODUCTION

Airborne radar systems capable of producing continuous images of the earth's surface are presently being studied as exploration tools for earth science investigations. The photo-like images obtained from side looking airborne radar (SLAR) systems contain data which have proven useful in the delineation of regional geologic structures, fracture patterns, and, in some areas, lithologic boundaries.

The use of remote sensors for geologic studies is by no means a new reconnaissance technique. Air photos have been used widely by geologists as aids in geologic investigations for years. The use of imaging radars as remote sensors is a relatively new development however, and its potential in geologic research is currently being studied. Investigations carried out to date indicate that radar imagery is an excellent source of geologic data. At present, radar imagery is being studied in detail in order to develop guidelines and techniques for accurate and reliable geologic interpretations.

A number of characteristics inherent to a SLAR system tend to emphasize many terrain features of interest to the geologist. The relatively coarse resolution of radar systems (when compared to conventional aerial photography) tends to emphasize the gross patterns of an area, while suppressing undesirable natural and cultural data. In addition radar energy impinging on the earth's surface at an angle produces areas of shadow (negligible return of radar energy) behind areas of elevated topography, and areas of high magnitude return from surfaces orthogonal to the radar signal (Figure 1). This results in what is essentially a three-dimensional presentation without the use of stereo techniques. Another factor is the synoptic view of radar imagery allowing the visual integration of terrain features over a considerable area of the earth's surface.

This paper summarizes a study concerned with an attempt to define criteria for the recognition and interpretation of geologic structures on radar imagery. The study was carried out on imagery of the Grand Canyon area, northern Arizona, where initial inspections of the image and geologic data indicated the possibility of a good correlation between radar lineaments and geologic structures. The purpose of the study was to determine if additional information could be gained from radar imagery which would be useful in the interpretation of similar structures in other areas.

The AN/APQ-97 side looking airborne radar system which produced the radar image used in the study was developed by the U. S. Army Electronics Command. It is a real aperture radar system operating in the K-band region of the electromagnetic spectrum. The area was flown by Westinghouse Corporation under contract to the National Aeronautics and Space Administration.

GEOLOGIC SUMMARY OF THE GRAND CANYON AREA

Introduction

The study was conducted in an area of approximately 325 square kilometers located in the Grand Canyon area of north-central Arizona (Figure 2). This region in the southwestern portion of the Colorado Plateau is a maturely dissected area underlain by nearly horizontal Paleozoic sedimentary rocks overlying an intensely deformed Precambrian basement sequence.

The study area lies within the region traversed by the Grand Canyon of the Colorado River and its tributaries, and occupies a position between the Kaibab and Coconino uplifts of the Colorado Plateau. Approximately 1,500 meters of relief exists between the steep-walled major canyons of the area and the adjacent plateaus. Precambrian sedimentary rocks underlie the major portion of the study area, while Precambrian sedimentary and meta-sedimentary rocks are exposed in the lower portions of the Grand Canyon. Mesozoic rocks are not found within the study area.

Stratigraphic Summary

The Precambrian rocks of the study area belong to the Archean and Algonkian systems, and are believed to be over 12,000 meters thick, (Maxon, 1966). The Archean rocks are highly deformed metasediments consisting in large part of schists and quartzites, while the Algonkian sedimentary section is only moderately deformed. Rocks of both systems have been intruded by granitic dikes (Figure 3). Paleozoic rocks of the area consist of approximately 1,200 meters of nearly horizontal, interbedded limestones, sandstones, and shales. The Paleozoic section rests unconformably on the Precambrian basement described above. The Paleozoic stratigraphy of the Grand Canyon area is summarized in Figure 3.

Structural Features

A southwest dipping homocline (average dip of 1.5°) of the Paleozoic sequence is the major structural feature of the Grand Canyon area. However monoclinal folds, normal faults, joints, Precambrian dikes, and Precambrian schistosity all contribute to well-developed NE-SW and NW-SE structural trends within the region.

Archean structures are indicative of extremely intense orogenic activity. The Archean schists are characterized by broad isoclinal folds trending northeast-southwest, having near-vertical schistosity and bedding. Jointing in the Archean section is nearly vertical and trends NW-SE. The Algonkian strata are neither highly faulted nor folded yet represent the deformation by stresses from the same directions as those which deformed the Archean rocks.

Paleozoic rocks of the study area reflect the stresses of the Late Cretaceous to mid Tertiary Laramide orogeny. The Colorado Plateau area was only gently deformed during the Laramide orogeny, however the stresses were responsible for the development of local faults and monoclinal flexures.

Hodgson (1961) summarized the relationship between the fracture pattern in the Precambrian and the Paleozoic rocks:

> "The major fracture trends, established in the basement complex in Precambrian time, whether joints or faults have persisted through time and through a fairly thick section of Paleozoic...sedimentary rocks. This persistence of the major elements of a Precambrian fracture pattern in younger rocks suggests strongly that the direction of jointing in younger rocks has been directly controlled or strongly influenced by these early fractures and the Precambrian pattern has been imposed consistently on each successive sedimentary rock unit."

Thus the NW-SE and NE-SW fracture trends appear to have been strongly defined in the Precambrian rocks, and were subsequently impressed on the gently deformed overlying sedimentary rocks, resulting in a section which was fractured in a uniform manner.

THE GEOLOGIC EVALUATION OF THE RADAR IMAGE

Introduction

Initial inspection of the radar image (Figure 4) of the study area suggested that considerable structural data were available. The most notable features of the image within the eroded canyon area are prominent NW-SE and NE-SW trending lineament sets. These lineaments sets are expressed as the narrow straight portions of the Grand Canyon and many of its tributaries.

Methods of Study

The study was divided into two phases; the first involved detailed examination and interpretation of the radar image of the area; the second phase consisted of compilation and evaluation of the published geological investigations from the study area. Reliability and extent of the radar data were determined from a careful comparison of the two sets of data. Faults, folds, and joint patterns from geologic maps and other publications were compared visually with the lineament trends obtained from the radar image. Rose diagrams were constructed relating lineament trends to the known fracture patterns of the area.

Geologic Field Data

Although geologic field data for the study was gathered solely from published reports, it was of sufficient quantity and detail to provide a sound basis for evaluation of the radar image.

Maxson's (1966) geologic map of the Bright Angel Quadrangle was used to locate the known faults of the study area. Hodgson's (1961) publication concerning jointing and fracturing was used to compare lineament trends with the known fracture patterns. Published reports by Maxson and Campbell (1933) and Van Gundy (1946) provided additional geologic data.

Results

Image A of Figure 5 indicates the results of the lineament analysis within the study area. Parallel to subparallel lineaments sets are recorded with NE and SW orientation.Lineaments indicated on the image range from nearly one cm. to over 8 cms. in length, representing structures on the ground ranging from 1 1/2 kilometers to over 16 kilometers in length. Image B of Figure 5 shows the major mapped faults indicated on Maxson's (1966) map of Bright Angel Quadrangle. Of the 18 prominent faults (all over 3 kilometers in length) selected for comparison with the radar data, 15 were interpreted as geologic structures on the initial SLAR interpretation. The 3 mapped faults which had not been found on the radar imagery were not well expressed topographically, and consequently were not emphasized on the radar image. All three of the faults which had been overlooked on the radar image were in areas of extremely high - low contrast of radar return in steep walled canyons. Any subtle contrasts which might exist across the faults are most likely masked.

In addition to the major faults, numerous smaller faults are present in the narrow inner gorge of the Grand Canyon. These were not discernable on the radar image due to either (1) extensive shadowing or (2) extremely high magnitude return caused by the steep walls of the inner canyon which were oriented normal to the incident energy.

A comparison of images A and B of Figure 5 indicates over 25 radar lineaments are present where no faults or fractures have been mapped by field workers. The radar lineaments may represent faults which occupy the eroded canyon bottoms, and which have not been discovered by ordinary geologic field methods, or alternatively the lineaments may be a surface representation of joint concentrations along a line where no large offsets of strata are present to indicate fracturing to field workers. In either case a fracture pattern is indicated on the SLAR image and is a logical location for field checks.

The rose diagram (Figure 6) summarizing radar lineament data from the Canyon study area indicates the lengths of lineaments with respect to their orientation. Figure 7 diagrams joints of the same area as mapped by Hodgson (1961), but on the basis of direction and frequency of joints rather than the length of a joint.

A comparison of these two data indicates field study of the joints provides more comprehensive detailed data on the fracture pattern of an area, whereas the radar interpretation emphasizes the gross pattern. However both rose diagrams show concentrations of lineaments or joints in NE-SW and NW-SE directions.

The monoclinal folds, Precambrian schistosity and Precambrian dikes which have been mapped by field workers were not identified on initial examination of the image and in fact were not identifiable through comparisons of the image with published field data. However in most cases the schistosity trend and dikes were not recorded on the image due to the confinement of exposures of Precambrian rocks to the shadowed zones in the inner gorge. In addition no radar data were found to aid in the identification of the monoclinal folds of the area. Whereas monoclinal folds are known to parallel a number of the lineament (fault) controlled canyons, no apparent differences were detected between faulted canyons with and those without adjacent monoclinal folds.

CONCLUSIONS

Comparison of radar derived structural data with published field data of the Grand Canyon area demonstrates the potential of radar imagery as a tool for geologic, fracture reconnaissance studies. In addition some of the limitations of SLAR for structural studies are demonstrated.

(1) A strong positive correlation exists between the major lineament patterns of the radar image and the major normal faults of the study area. Although the jointing pattern shows strong parallelism with the radar lineaments, the correlation with faults is indisputable. It is therefore concluded that the NE-SW and NW-SE trending faults are responsible for the prominent structural grain as shown by the radar lineaments, and the correlation of joints with the lineaments indicates the close relationship between the directions of jointing and faulting.

(2) The lineaments interpreted as faults or joints yet not mapped as such on the geologic maps are the locations of possible structures, and therefore excellent leads for further field checks. Radar imagery thus provides a reliable source of reconnaissance data, even in areas where considerable geologic exploration and mapping have been accomplished.

(3) In this area of considerable relief, the look-direction of the SLAR system (the direction normal to the flight direction) has an effect on the quantity and quality of the information available on radar imagery

(MacDonald, 1969). Since the radar data were obtained on a flight path parallel to the inner gorge of the Grand Canyon, virtually no data were available from the area where Precambrian rocks are exposed.

(4) The interpretation of geologic structures on a SLAR image is a function of the scale of the image, and the size of the structural feature. Lineaments on the study image with a length less than approximately 1.5 kilometers were generally difficult to interpret due to their irregular appearance. However if a longer lineament is studied in increments of 1.5 kilometers, many portions appear as irregular features. Thus it is concluded that the interpretation of the short lineaments is of questionable reliability, and the increasing length of a lineament lends creditability to a structural interpretation.

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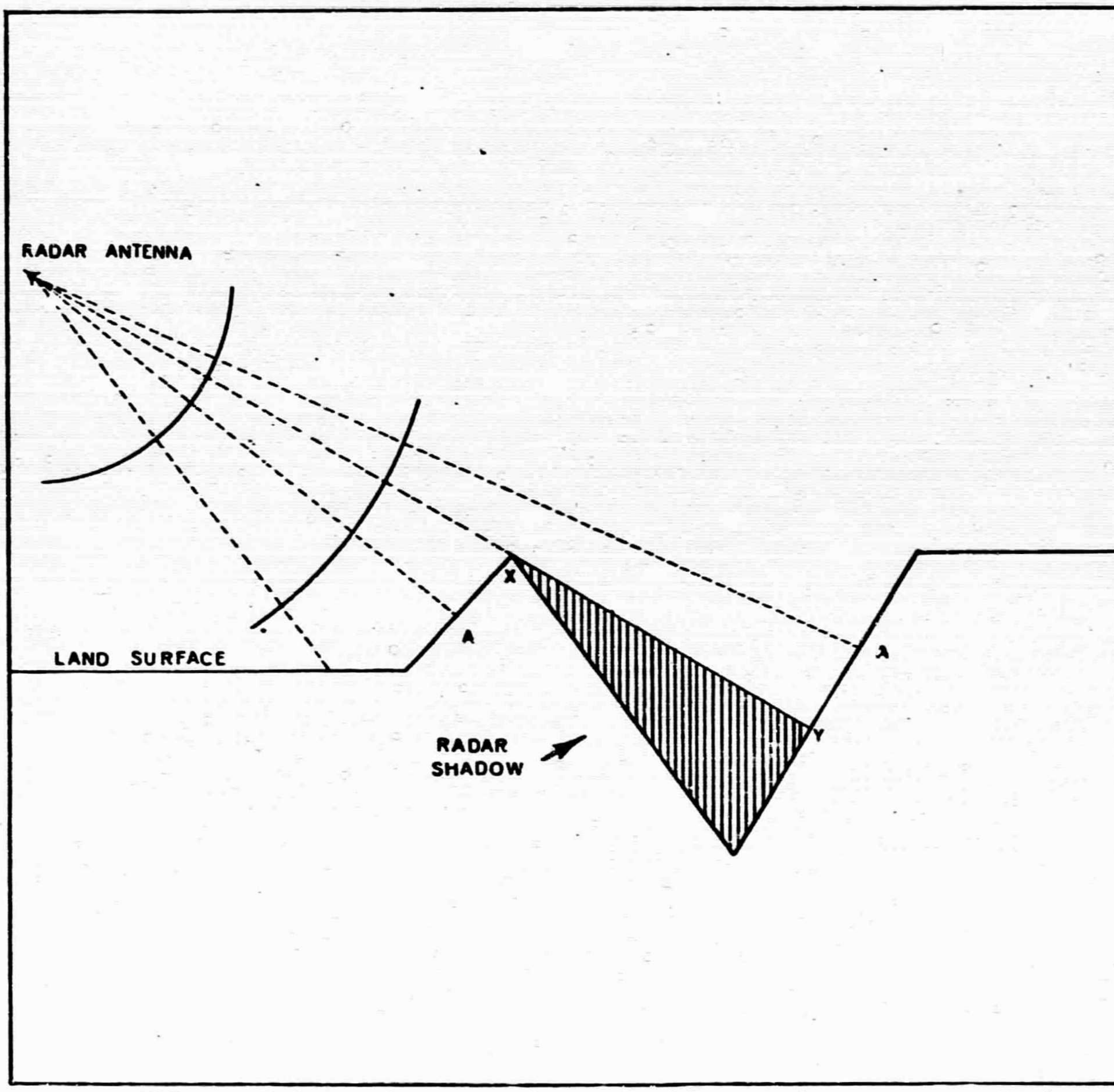

FIGURE I. Effect of irregular terrain on incident radar energy. Peak at X masks opposite valley wall below point Y, resulting in radar shadow zone as shown. Areas marked with an A are approximately orthogonal to the incident energy and consequently return a large proportion of the incident energy toward the antenna. Curved lines mark positions of advancing wave fronts of the radar energy.

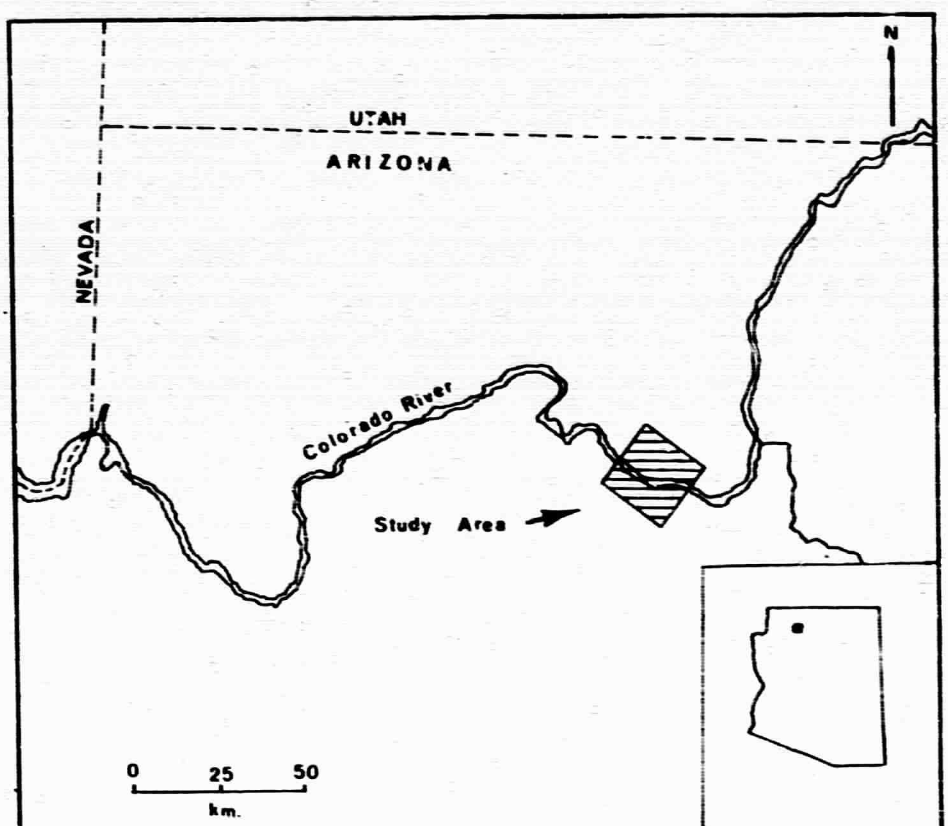

FIGURE 2. Location of the study area.

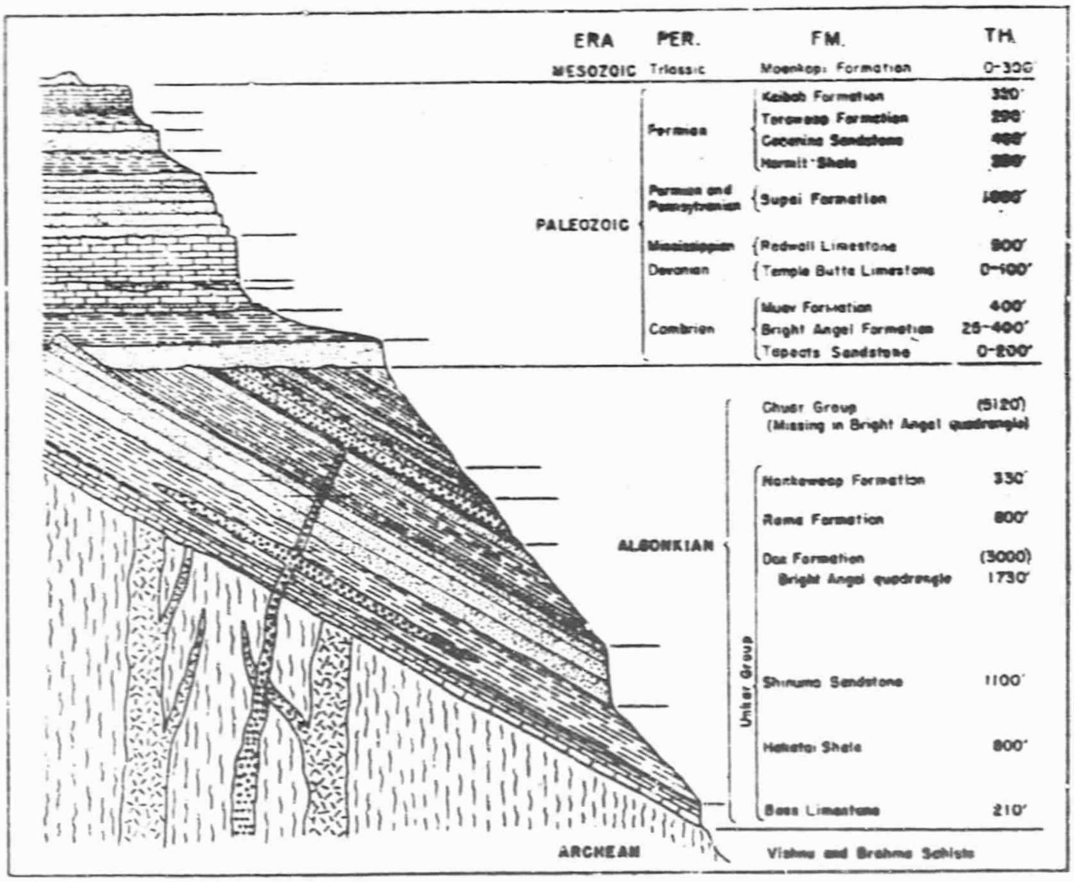

Figure 3. Generalized stratigraphic summary of the Grand Canyon area. From Maxson, 1961.

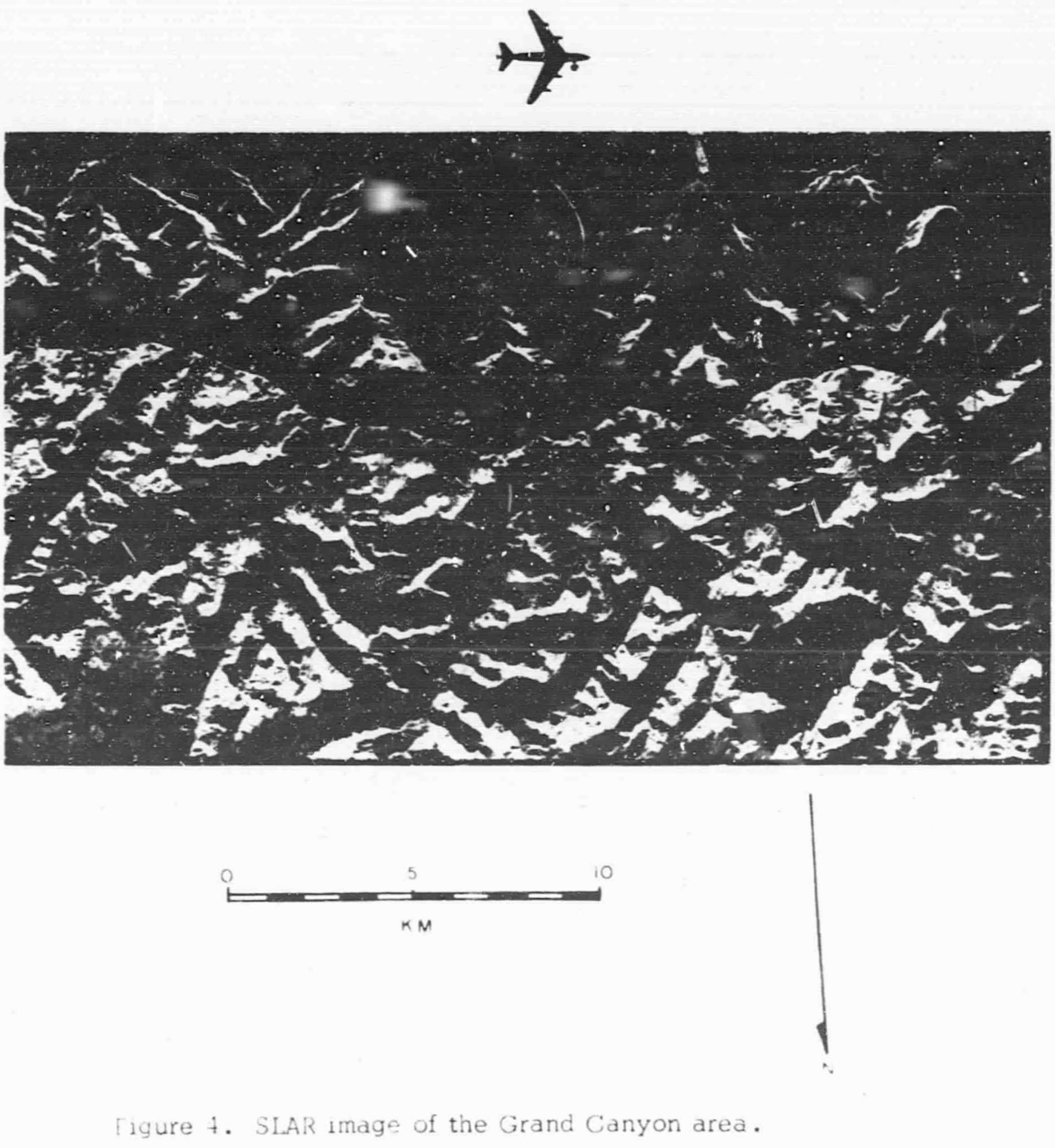

Figure 4. SLAR image of the Grand Canyon area.

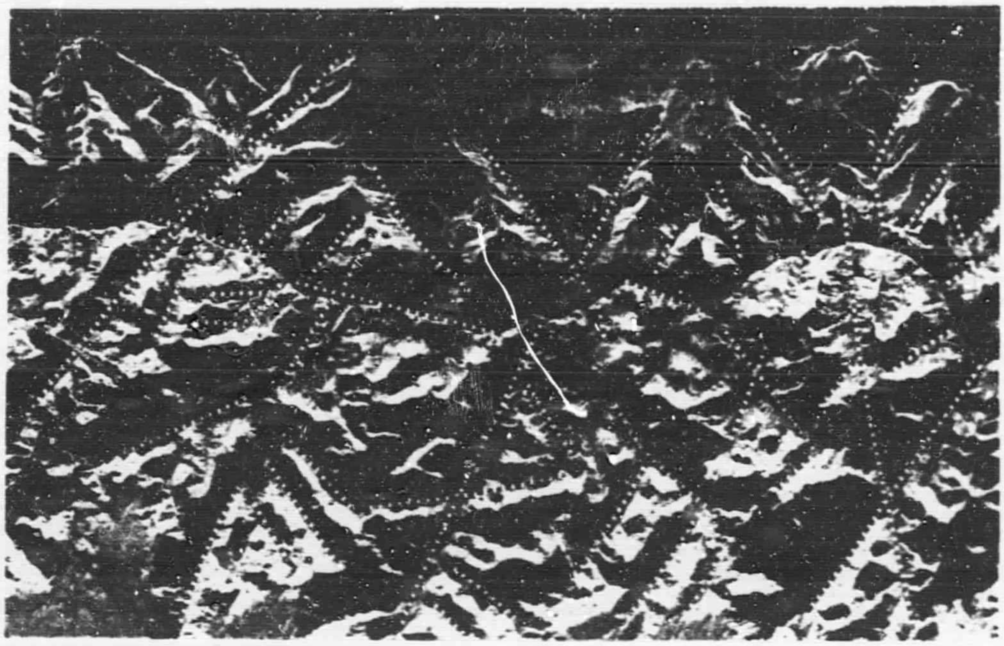

Figure 5, Image A, Radar lineaments of the Grand Canyon study area.

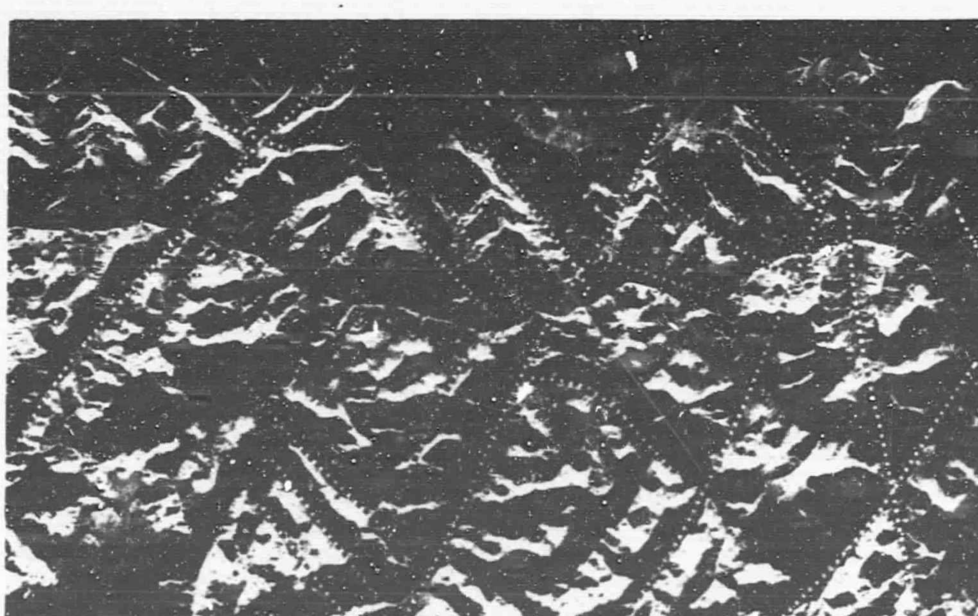

Figure 5, Image B, Major mapped faults of the Grand Canyon area.
From Maxson, 1966.

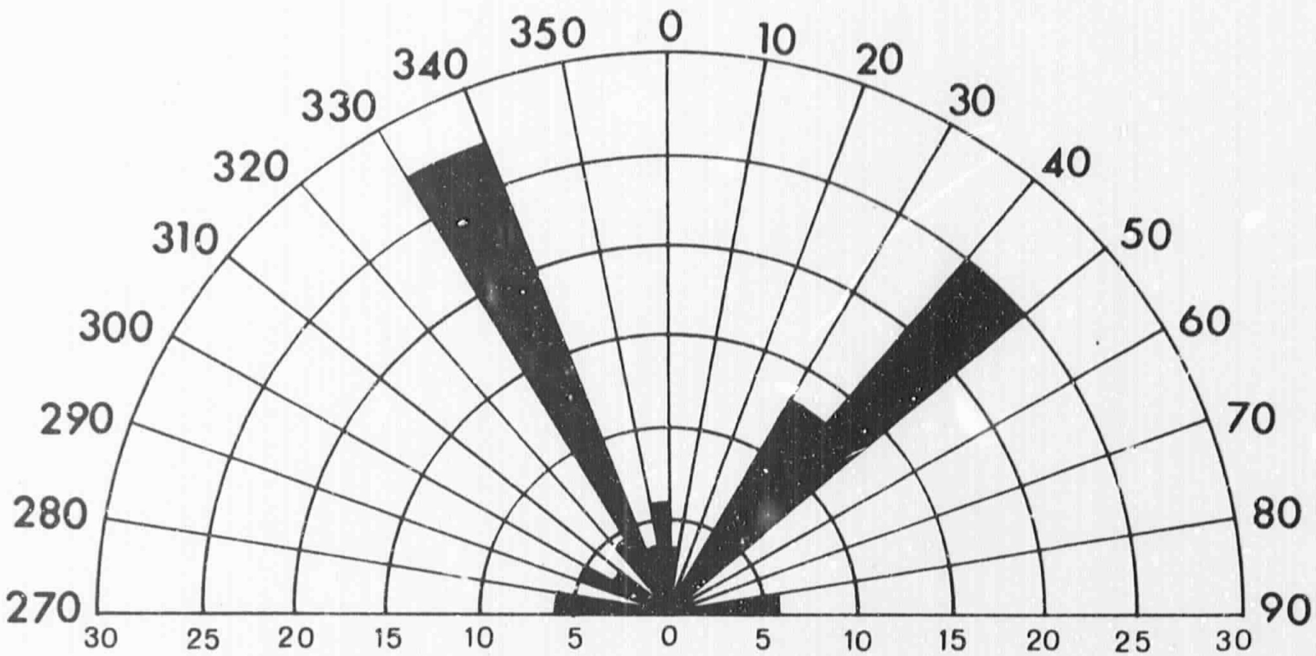

Figure 6. Rose diagram of radar lineament data, Grand Canyon Arizona. Relative lengths of radar lineaments in miles plotted with respect to bearing.

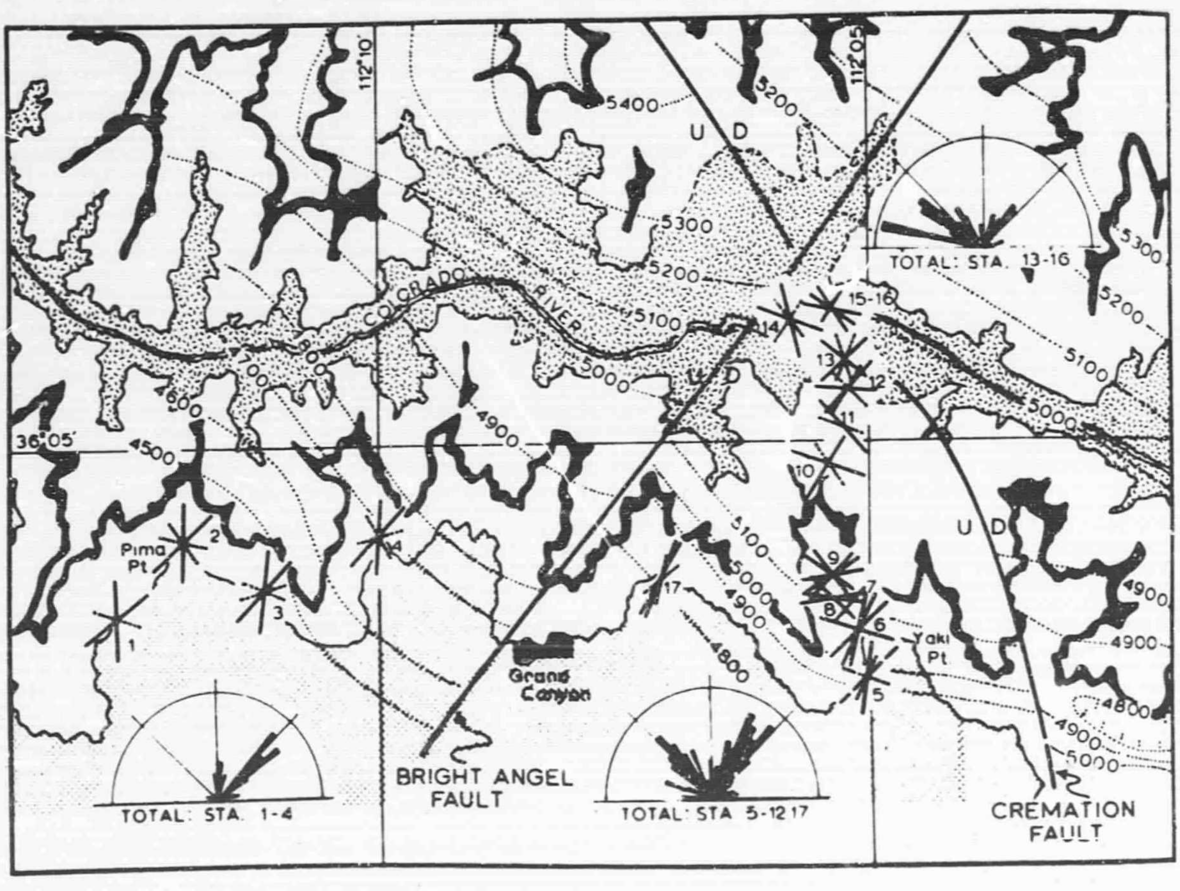

Figure 7. Jointing data from the Grand Canyon area.
From Hodgson, 1961.