(NASA-CR-169289) FIREX MISSION REQUIREMENTS DOCUMENT FOR NONRENEWABLE RESOURCES (Jet Propulsion Lab.) 89 p HC A05/MF A01 CSCL 22A

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TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. JPL Pub. 82-46	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle FIREX Mission Requirements Document for Nonrenewable Resources		5. Report Date June 15, 1982
		6. Performing Organization Code
7. Author(s) T. Dixon, F. Carsey		8. Performing Organization Report No.
9. Performing Organization Name and Address JET PROPULSION LABORATORY California Institute of Technology 4800 Oak Grove Drive Pasadena, California 91109		10. Work Unit No.
		11. Contract or Grant No. NAS 7-100
		13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address NATIONAL AERONAUTICS AND SPACE ADMINISTRATION Washington, D.C. 20546		14. Sponsoring Agency Code RD 151 J-146-40-01-04-00
15. Supplementary Notes		

16. Abstract

This document describes the proposed mission requirements and a proposed experimental program for a bilateral U.S./Canadian satellite synthetic aperture radar (SAR) system named FIREX (Free-Flying Imaging Radar Experiment) for nonrenewable resources. The recommended spacecraft minimum SAR system is a C-band imager operating in four modes: 1) low look angle (15°-20°), HH-polarized, 2) intermediate look angle (30°-35°), HH-polarized, 3) intermediate look angle (30°-35°), HV-polarized, and 4) high look angle (60°-65°), HH-polarized.

This single-wavelength system is practicable and would be a powerful research tool for use in testing the utility of SAR in geological mapping. Its usefulness would be further enhanced by the addition of a fifth mode-an L-band HH-polarized SAR operating at an intermediate look angle of 30°-35°. The fifth mode would permit a wavelength ratio of 4:1 to be used in geologic mapping experiments of surface features which are strongly dependent on wavelength. This SAR system is complementary to other future spaceborne imagers such as the Thematic Mapper on Landsat-D. A near-term aircraft SAR-based research program is outlined which addresses specific mission design issues such as preferred incidence angles or polarizations for geologic targets of interest.

17. Key Words (Selected by Author(s)) Geosciences and Oceanography (General) Earth Resources	18. Distribution Statement Unclassified - Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	87	

JPL 0184 11/80

FIREX Mission Requirements Document for Nonrenewable Resources

June 15, 1982

NASA
National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

This publication was prepared by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

ABSTRACT

This document describes the proposed mission requirements and a proposed experimental program for a bilateral U.S./Canadian satellite synthetic aperture radar (SAR) system named FIREX (Free-Flying Imaging Radar Experiment) for non-renewable resources. The recommended spacecraft minimum SAR system is a C-band imager operating in four modes:

1. Low look angle (15°-20°), HH-polarized
2. Intermediate look angle (30°-35°), HH-polarized
3. Intermediate look angle (30°-35°), HV-polarized
4. High look angle (60°-65°), HH-polarized

This single-wavelength system is practicable and would be a powerful research tool for use in testing the utility of SAR in geological mapping. Its usefulness would be further enhanced by the addition of a fifth mode - an L-band HH-polarized SAR operating at an intermediate look angle of 30°-35°. The fifth mode would permit a wavelength ratio of 4:1 to be used in geologic mapping experiments of surface features which are strongly dependent on wavelength. This SAR system is complementary to other future spaceborne imagers such as the Thematic Mapper on Landsat-D. A near-term aircraft SAR-based research program is outlined which addresses specific mission design issues such as preferred incidence angles or polarizations for geologic targets of interest.

FOREWORD

This document is one of a series describing the Free-Flying Imaging Radar Experiment (FIREX) mission requirements:

Science Requirements for Free-Flying Imaging Radar (FIREX) Experiment for Sea Ice, Renewable Resources, Nonrenewable Resources, and Oceanography, JPL Publication 82-32.

Sea Ice Mission Requirements for the U.S. FIREX and Canada RADARSAT Programs, JPL Publication 82-24.

FIREX Mission Requirements Document for Nonrenewable Resources, JPL Publication 82-46.

FIREX Mission Requirements Document for Renewable Resources, JPL Publication 82-47.

PREFACE

The FIREX (Free-Flying Imaging Radar Experiment) Non-Renewable Resources Mission Requirements Document (MRD) was prepared by the members of the FIREX Non-Renewable Resources Study Team listed below.

FIREX Non-Renewable Resources Study Team

Dr. Keith R. Carver	Chairman; NASA Headquarters, Washington, D.C.
Dr. Anthony W. England	Co-Chairman; NASA Johnson Space Center (JSC), Houston, Texas
Dr. Andrew Blanchard	Texas A&M University, College Station, Texas
Dr. Aderbal Correa	CONOCO, Inc., Golden, Colorado
Dr. Charles Elachi	Jet Propulsion Laboratory, Pasadena, California
Dr. Dennis Krohn	U.S. Geological Survey, Reston, Virginia
Dr. Harold C. MacDonald	University of Arkansas, Fayetteville, Arkansas
Dr. James V. Taranik	NASA Headquarters, Washington, D.C.

The team held its first meeting on May 20-21, 1981, at the NASA Goddard Space Flight Center. An outline of the MRD was prepared, and writing assignments were made. Dr. England wrote the first draft and Dr. Carver, after receiving comments and additional material from team members, assembled this final document. The team gratefully acknowledges the material on radar simulations contributed by Dr. Verne Kaupp of the University of Arkansas.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. EXECUTIVE SUMMARY

This Mission Requirements Document, prepared by the U.S. Non-Renewable Resources Study Team, summarizes (1) the major potential non-renewable resources applications objectives for orbital free-flyer synthetic aperture radar (SAR) imagery acquired at either L-band (1.275 GHz) and/or C-band (5.3 GHz), (2) key radar parameters and specific research issues (e.g., recommended angles, frequencies, or polarizations) which must be addressed in order to adequately specify the SAR satellite mission requirements, (3) an experimental program using aircraft SAR data which could address those key research issues, and (4) the recommendation of the mission requirements for a SAR to be used in a future satellite-based research program. This satellite program is referred to in this document as FIREX (Free-Flying Imaging Radar Experiment).

A. POTENTIAL NON-RENEWABLE RESOURCES APPLICATIONS OBJECTIVES

The Non-Renewable Resources Study Team proposes three objectives for FIREX: (1) to complete the investigation of satellite radar's sensitivity to topography, (2) to develop the use of backscatter radiance as a discriminator among geologic features, and (3) to conduct radar stereo imaging research. The Study Team emphasizes that these objectives require the highest possible geometric and radiometric control of the radar data.

The primary recognized advantage of radar in remote sensing geology is radar's sensitivity to topography. This sensitivity is greatest at incidence angles less that 25° and greater tnan 60°. Seasat provided high quality radar data at a 22° incidence angle. FIREX should first provide calibrated registered imagery at a high look angle of 60°-65° for use in structural mapping. Spaceborne SAR sensitivity to topography should be further explored by additionally imaging at an intermediate look angle of 30°-35°; the combination of intermediate and high look angle data permits 30° convergence stereo which has been shown to be a powerful tool in geomorphology. Finally, a low look angle mode of 15°-20° should be included to permit studies of subtle topographic expression in areas of low relief.

At a single wavelength, single look angle and single polarization, a given geologic unit may not have a unique signature since its radiometric brightness on an image depends on local slopes, surface moisture, vegetation cover, etc. Geologic interpretation of radar imagery is based on the analysis of image recognition elements which include tone, texture, shape, pattern, and context. However, when it is possible to vary the wavelength, or incidence angle, or polarization, a much more powerful imaging capability is made available because independent looks are acquired which can be used to discriminate among different geologic structures.

Radar backscatter radiance has considerable potential for discrimination among soil and rock types, and geobotanical features. Topographic effects are a confusion factor for this application so that intermediate look angles (30°-35°) are preferred. Theory and field studies highlight the importance for discrimination based upon backscatter radiance of acquiring both like- and cross-polarized data. Radar backscatter radiance varies with surface geometry and moisture content while infrared reflectance varies primarily with surface chemistry. The essential independence of these two processes suggests that radar and infrared reflectances should be combined for multicomponent analyses. The experiment would be further enhanced by a second radar wavelength to permit microwave as well as infrared spectral discrimination.

B. KEY RADAR PARAMETER RESEARCH ISSUES

A mission requirements specification for a SAR satellite must include the desirable frequency(ies), angle(s) of incidence, polarization(s), resolution(s), number of looks and revisit interval(s). Other radar parameters of particular importance to the geologist include swath width, calibration, dynamic range, registration, and multiple looks.

In order to specify these parameters for a meaningful satellite radar geology experiment, the following research issues must be addressed:

1. Sensitivity to topography, vs. frequency, polarization, resolution, and angle of incidence.

2. Sensitivity to surface roughness and vegetation cover, vs. frequency, polarization resolution and angle of incidence.

3. Sensitivity to soil moisture, vs. frequency, resolution and angle of incidence.

It is stressed that these issues can only be addressed with high quality (calibrated and registered) multiparameter SAR imagery over wide swaths. From a practical viewpoint, some of this work can be done using airborne multiparameter SAR's and, indeed, specific experiments are proposed herein to utilize airborne SAR data. But even the best airborne SAR data suffers from a wide variation in incidence angle over the swath width so that suturing 10-20 km wide images to form a 100 km mosaic presents formidable problems when large-swath regional context images are needed. This serious angle-dependence of airborne SAR data means that only spaceborne SAR data over 75-150 km swath widths, with a relatively constant angle of incidence, are adequate to address the utility of SAR for regional geologic mapping applications.

C. EXPERIMENTAL PROGRAM

An experimental program plan has been devised to address the specific radar parameter research issues discussed above, and concentrates on the use of multiparameter airborne SAR data obtained over eight sites in the United States. Five of these sites are for arid or semi-arid radar geology studies and three are for vegetated terrain.

As initially conceived, the plan envisioned the use of sets of L-, C-, and X-band calibrated SAR images, to be provided by the Canadian CV-580 SAR system. However, it was subsequently learned that acquisition and processing of CV-580 SAR data over U.S. test sites had to be handled contractually through the Environmental Research Institute of Michigan (ERIM) and that the associated costs of coverage of the recommended sites would be prohibitively high. Airborne SAR data can also be obtained at

L-band using the JPL CV-990 SAR system, and at X-band and C-band using the NASA/JSC SAR system. However, in FY 82, the JSC X- and C-band SAR's will not be available for use due to a planned configuration change.

Nonetheless, the recommended sites and experiments are included in the event that other arrangements for aircraft coverage can be made. It should be noted that these experiments are important not only in the context of the U.S.-Canadian mission requirements study, but also for other NASA-sponsored research investigations as well.

D. SUMMARY OF PRELIMINARY MISSION REQUIREMENTS

The preliminary recommendations of the Study Team for a FIREX configuration is based upon (1) a tentative understanding of the roles played by wavelength, incidence angle, and polarization in radar imagery, (2) valuable experience gained through both Seasat L-band SAR imagery as well as aircraft L-band, X-band, and Ka-band SAR imagery over various geologic test sites, and (3) the collective judgments of both the Study Team and a much larger radar geology community as discussed for example in the recent Snowmass Report [Snowmass Report, 1979]. The Study Team began with the baseline FIREX mission (C-band, 35^{o}-45^{o}, HH), and developed four increasingly ambitious radar system configurations that were consistent with the radar parameter research issues and applications objectives discussed above.

The recommended mission requirements are summarized in Table 1:

TABLE 1

Recommended Mission Requirements

SAR Parameter	Recommended Configuration
o Frequency	C-band
o Resolution	30m
o Noise equivalent σ^{o}	-35dB
o Polarization mode isolation	25dB
o Swath Width	150km (1 channel)
	75km (2 channels)
	50 km (3 channels)
Low Angle Mode	
o Look Angle	15^{o}-20^{o}
o Number of azimuth looks	TBD
o Polarization	HH
o Revisit interval	seasonal
Intermediate Angle Mode	
o Look Angle	30^{o}-35^{o}
o Number of Azimuth looks	TBD
o Polarization	HH + HV
o Revisit interval	seasonal
High Angle Mode	
o Look Angle	60^{o}-65^{o}
o Number of azimuth looks	TBD
o Polarization	HH
o Revisit interval	TBD

The low-angle mode gives an enhanced sensitivity to topography, where subtle slope changes are depicted with expanded contrast. This region is best for low-lying rough terrain, since layover and compression will severely distort mountainous terrain.

The intermediate-angle mode, using both like- and cross-polarized data, is at an intermediate angle where sensitivity to topography is minimized and where slope effects can be minimized in studies of rock types and geobotanical anomalies. Furthermore, when taken in combination with the high-angle data mode, 30° convergence stereo pairs would be obtained as a powerful tool in geomorphological studies.

The high-angle mode is useful for topographic mapping, with no layover and reduced slope distortion and minimal shadowing.

II. INTRODUCTION

This preliminary version of a Mission Requirements Document (MRD) has been prepared by the U.S. Non-Renewable Resources Study Team (NRR ST) in response to a request by the National Aeronautics and Space Administration (NASA) as a component of the bilateral study of the U.S. (NASA) and Canada (Department of Energy and Mineral Resources - DEMR) to define the parameters which are optimum for a spaceborne orbital free-flyer SAR. A similar document is being prepared by the parallel efforts of the Canadian Non-Renewable Resources Study Team, and it is anticipated that the essential recommendations of both teams will be summarized and compared in a jointly authored MRD to be available in 1982.

The request for this document was generated as a result of discussions in 1980 between representatives of DEMR in Canada and NASA in the U.S., which concluded that both organizations have a mutual interest in undertaking bilateral studies to define a possible future joint NASA/DEMR SAR satellite program which would satisfy both U.S. and Canadian requirements. These discussions resulted in the signing on November 26, 1980, of a bilateral plan to jointly conduct a 21 month (January 1981 to October 1982) Mission Requirements Study to define both research and operational requirements that might support such a possible future program. Four major applications areas for study were identified: Ice, Oceans, Non-Renewable Resources and Renewable Resources. It was agreed that Canada would form a study team for each of these areas and that the U.S. would also form four parallel teams in each area. Furthermore, each team would develop either separate and/or bilateral MRDs. A bilateral study schedule was developed, which requested that the preliminary MRD be available by May 1981, and that the final MRD be available by January 1982. It was anticipated that certain key SAR parameters could not be specified with the currently available data base and that a limited-duration aircraft-supported experimental program might be necessary in order to resolve optimum frequencies, incidence angles, polarizations, revisit times, etc., necessary to specify the best set of mission requirements for a free-flyer orbital SAR.

Prior to this activity, a study (called the SURSAT study) was performed by Canadian Astronautics, Ltd., in which the engineering feasibility was investigated of designing a SAR satellite which could provide routine operational monitoring of ice dynamics in the Canadian Arctic Sea. As a result of this study and subsequent analyses by the Canada Centre for Remote Sensing (CCRS), a baseline SAR design was selected which specified multiple coverage by three separate but identically-configured C-band SAR satellites, HH-polarized, with an orbital altitude of 675 km. This same SURSAT report also studied the feasibility of an L-band SAR and lists similar parameters for it. The selection of a C-band baseline SAR design was made by CCRS, with prime emphasis on operational monitoring of sea ice dynamics for use by the shipping industry.

The U.S. Non-Renewable Resources Study Team held its first meeting on May 20-21, 1981, at NASA Goddard Space Flight Center and was chaired by Dr. Keith R. Carver, of NASA Headquarters. Other ST members were Dr. Anthony W. England (Co-chairman, NASA Johnson Space Center), Dr. Harold C. MacDonald (University of Arkansas), Dr. Charles Elachi (Jet Propulsion Laboratory), Dr. Aderbal Correa (CONOCO), Dr. Andrew Blanchard (Texas A&M University) and Dr. James Taranik (NASA Headquarters). At this initial meeting, the team was instructed to consider only L-band and/or C-band orbital SARs, to provide a priority-ranked list of applications or research objectives, to identify any needed experimental programs which would specifically address unresolved issues, and to form a preliminary but considered opinion as to what the SAR parameters or range of parameters would likely be.

The NASA acronym for this program is FIREX (Free-flying Imaging Radar Experiment), and in the Canadian reports the program is known as the RADARSAT study. If the bilateral Mission Requirements Study results in a decision to proceed with a jointly funded and managed SAR free-flyer, the name RADARSAT would be used. If this decision is not made, then the name FIREX would be used as a generic acronym for a NASA-sponsored free-flyer SAR and RADARSAT would describe a Canadian-sponsored separate free-flyer SAR.

III. BACKGROUND

Geologic mapping is fundamental to all geologic investigations whether the objective is energy or mineral resource exploration and management, or the delineation of geologic hazards associated with nuclear power plants and nuclear waste repositories. The geologic map is an interpretation of the geology based on limited data. Remote sensing supports geologic mapping by reducing the uncertainties through:

(a) Providing a relatively inexpensive means for placing local studies in a regional geologic context;

(b) Providing a relatively inexpensive means for rapid identification of key field areas where more detailed and costly studies might prove fruitful; and

(c) Providing a unique means for mapping geologic features such as altered soils, pervasive but subtle structures, or geobotanical anomalies.

Because the process of geologic mapping is common to most geologic problems, it is artificial to identify specific remote sensing technologies with particular geologic applications. That is, if the product of a remote sensing technique, such as radar geology, is geologic information, then that technique will be applicable in most geologic investigations. Therefore, rather than being concerned with specific geologic applications for radar, R&D in radar geology is primarily concerned with radar's contribution to geologic mapping in general.

The advantages of spaceborne radar in geological mapping are:

(1) All-weather, day-night operation

(2) Selectable frequency or wavelength

(3) Multiple polarization

(4) Control of look direction and look angle for improved terrain interpretation

(5) Wide area coverage - synoptic view

(6) High resolution with radar systems comparable with most remote sensing systems

(7) Enhancement of landforms provides rapid formulation of geologic models

(8) Terrain texture discrimination

(9) Stereo capability

(10) Digital capability for multisensor data merge

(11) Provides an accurate base map

The quantification of these advantages has not been equally developed through prior scientific investigations. Military research led to commercial exploitation of radar's all-weather capability and its sensitivity to topography. The military has only recently begun to study radar backscatter from soil, rock, and vegetation, and has shown little interest in the effect upon backscatter of soil and plant moisture. Civilian research, although constrained by limited access to high quality radar data, is beginning to answer the practical question of the uses of wavelength, polarization, incidence angle, sensitivity, and temporal coverage in radar geology.

Commercial aircraft radars produce images that look like low sun angle, haze free, aerial photographs. These airborne radar systems are derivatives of military radars designed for all weather capability and sensitivity to topography. The image products are map-like and often resolve features having dimensions of only a few meters. However, the images lack fidelity both in geometry and in backscatter radiance. The geometric distortion is generally greater than 100m so that pixel by pixel registration with data having even moderate resolution, Landsat data for example, is difficult. The system-induced variability in apparent backscatter radiance may exceed several dB so that natural variations in backscatter radiance are masked. Without geometric or radiometric control, stereo projection or complex digital information extraction is difficult. That is, current commercial systems produce cosmetically pleasing images for qualitative geologic analyses in terms of form and texture. The central research issue in radar geology concerns the benefit of digitally-processed, calibrated radar data at one or more wavelengths and polarizations. The consensus among the radar geology community is that a satellite radar experiment, such as FIREX, could provide the experience, the quality of data, and the test of theory necessary to refine radar image processing and data merging techniques for enhanced recognition of geologic form, and also necessary to develop machine processing techniques for spectral discrimination among geologic features. These views are documented in a series of reports (Appendix A). Our recommendations are in substantial agreement with the recommendations of those earlier reports.

IV. EXPERIMENT OBJECTIVES

The general research objectives in radar geology are to develop the science and technology for more effective application of radar to geologic problems, and to place calibrated, geometrically rectified experimental radar data in the hands of innovative users so that techniques for applying these new data will be developed and disseminated. Specific objectives for FIREX are to acquire digital satellite data having high geometric and radiometric fidelity for the purposes of (1) developing enhanced sensitivity to topography, (2) developing an understanding of backscatter radiance from the earth's surface as geologically useful analytical parameters, and (3) radar stereo research.

A. SENSITIVITY TO TOPOGRAPHY

Sensitivity to topography is acknowledged as the primary geologic advantage of radar. Figure 1 shows typical backscatter cross sections, σ^o, versus incidence angle for several natural surfaces. Variation in slope causes the greatest variation in σ^o at incidence angles less than 25^o or greater than 60^o.

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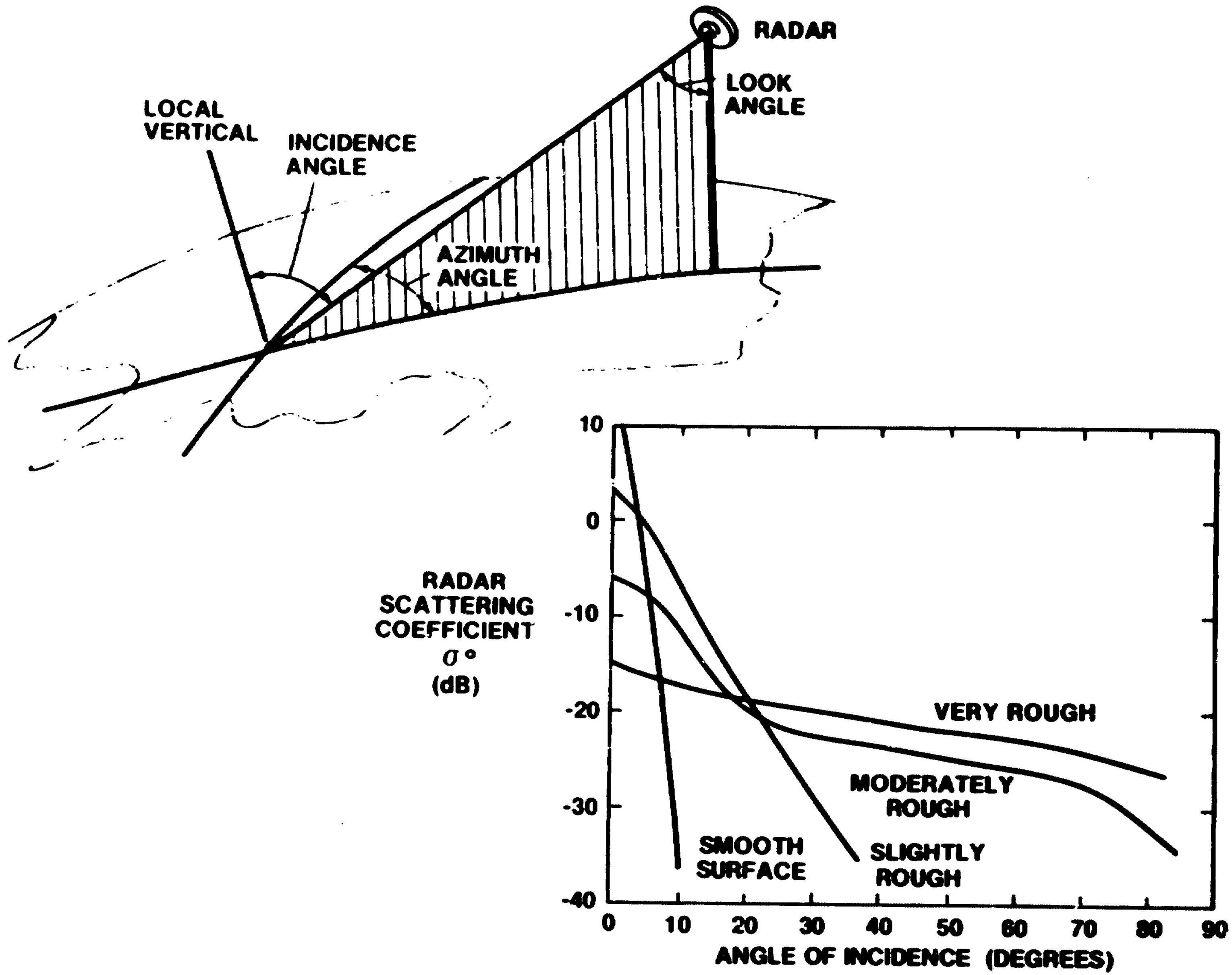


Fig. 1. Typical radar scattering coefficients vs. incidence angle for several natural surfaces.

A.1 Computer-aided Simulations of Radar Imagery

One relatively inexpensive means for obtaining insight into the effect of both incidence angle and azimuth angle on radar imagery is to simulate coherently illuminated SAR images of earth features with known topographic contours. This technique was initially reported by Holtzman, et. al., [1976] who used a symbolic representation of a site at Pickwick Dam, Tennessee, along with a point scattering method of simulating X-band HH-polarized imagery obtained with empirical elevation and backscatter data and by then comparing to actual X-band HH-polarized SAR imagery obtained with an airborne AN/APD-10 radar. More recently, Kaupp, et. al., [1981] have mathematically simulated radar imagery of a simple landscape model of a breached anticline and syncline, with a maximum elevation (along the crest line) of 100m, and slope angles ranging from 8° (on the nose of the anticline) to 60° (for very steep escarpments), as shown in Figure 2. For further details of the mathematical model and assumptions, the reader is referred to Kaupp, et.al., [1981]. Empirically measured backscatter data were used where possible to determine the angular sensitivity of radar backscatter.

Figures 3-6 are simulated radar images created from azimuth looks (to the west, south, east, and north) at the geologic terrain model of Figure 2. These figures illustrate how the radar portrayal of a given scene changes as the viewing aspect angle, or radar look direction changes. Each of the figures contains three images simulated for different radar incidence angles; 23°, 35°, and 65° left to right, respectively. The three images in each figure show how the radar portrayal of a given scene and look direction changes with the radar incidence angle.

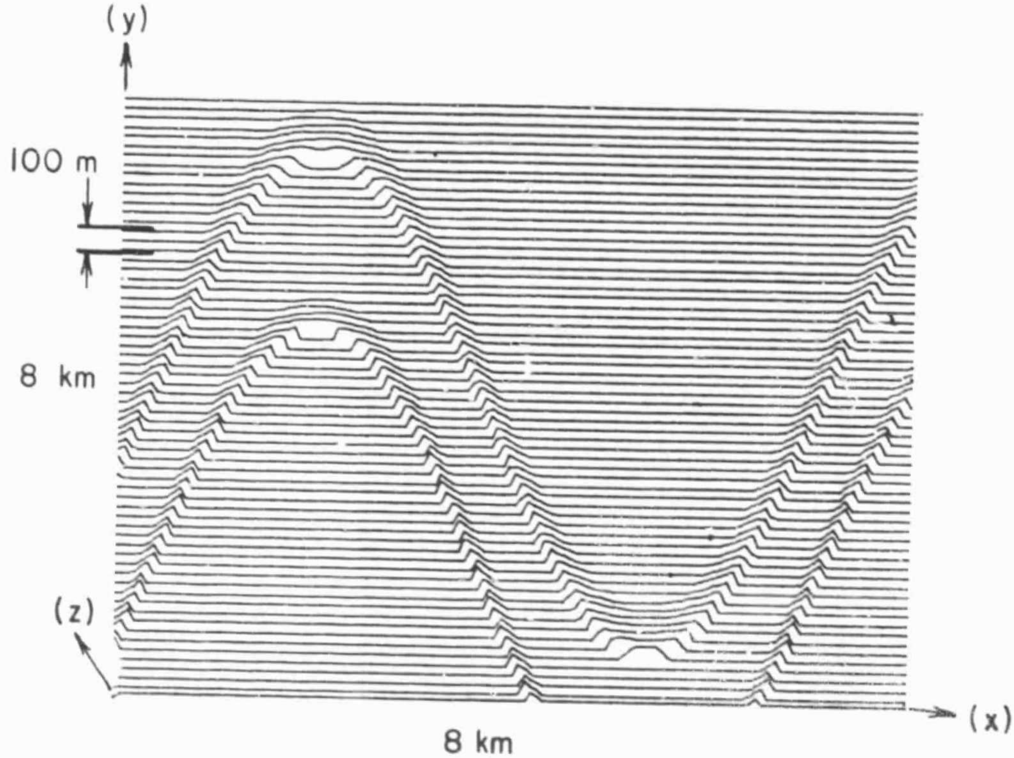
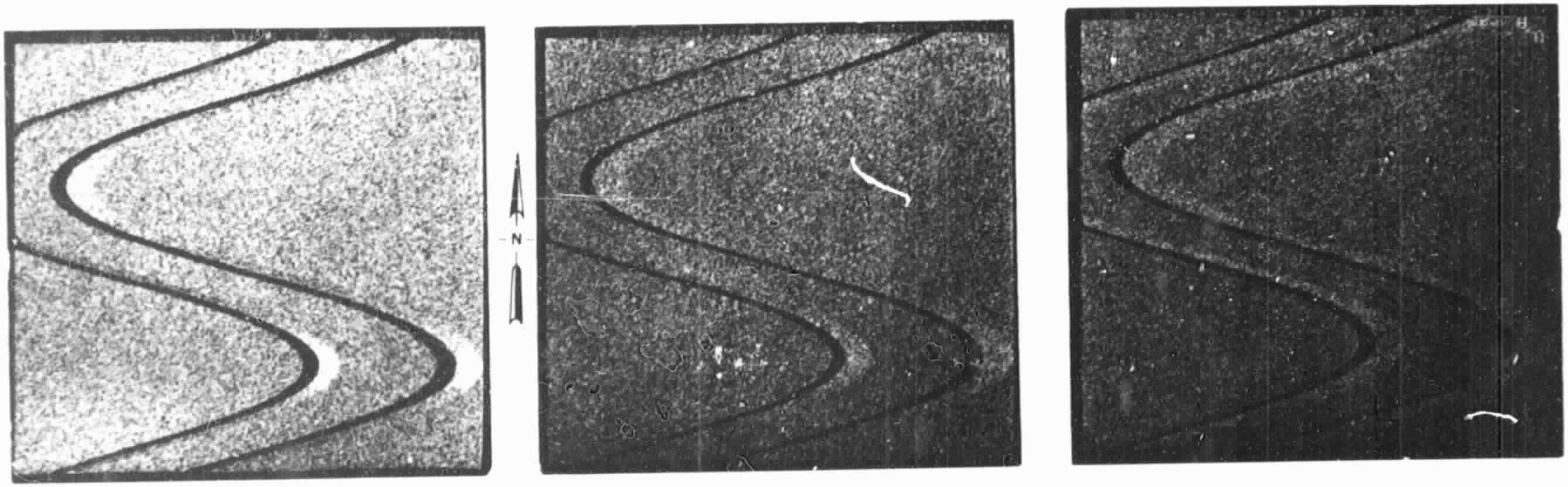


Figure 2. Landscape model (anticline/syncline) used for radar simulations of Figures 3-6. After Kaupp, et.al., 1981.

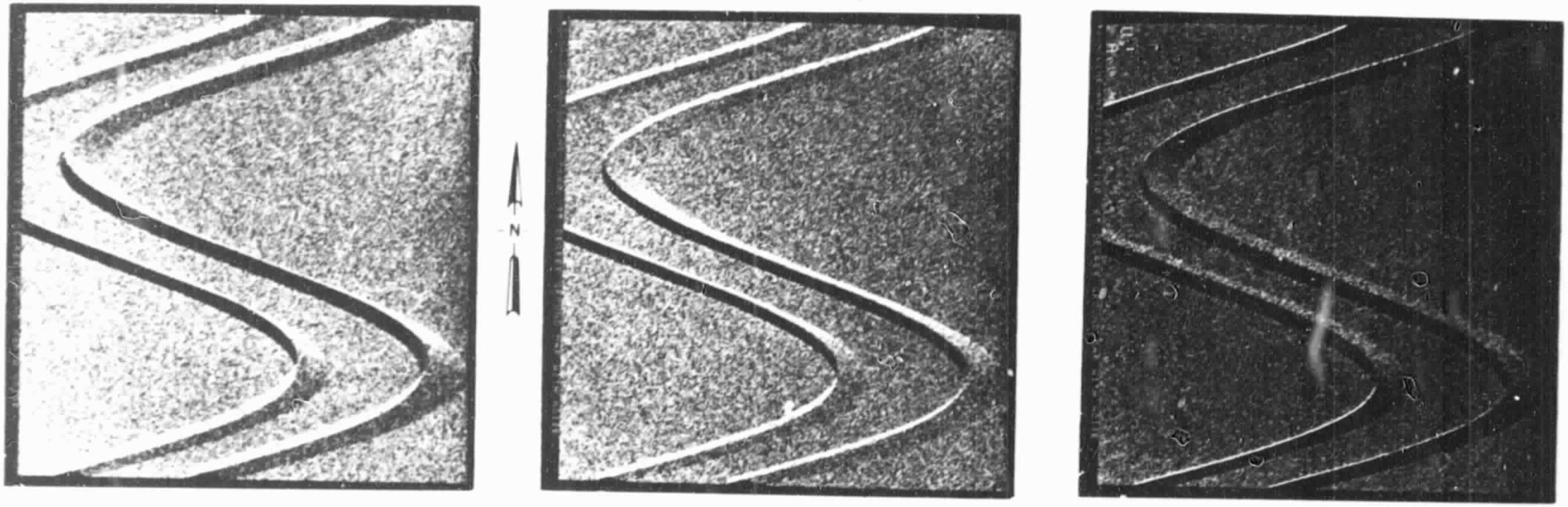


23° Angle of Incidence

35° Angle of Incidence

65° Angle of Incidence

Figure 3 Simulated Ground Range Radar Images of Anticline/Syncline Geologic Terrain Model (Look Direction is West)

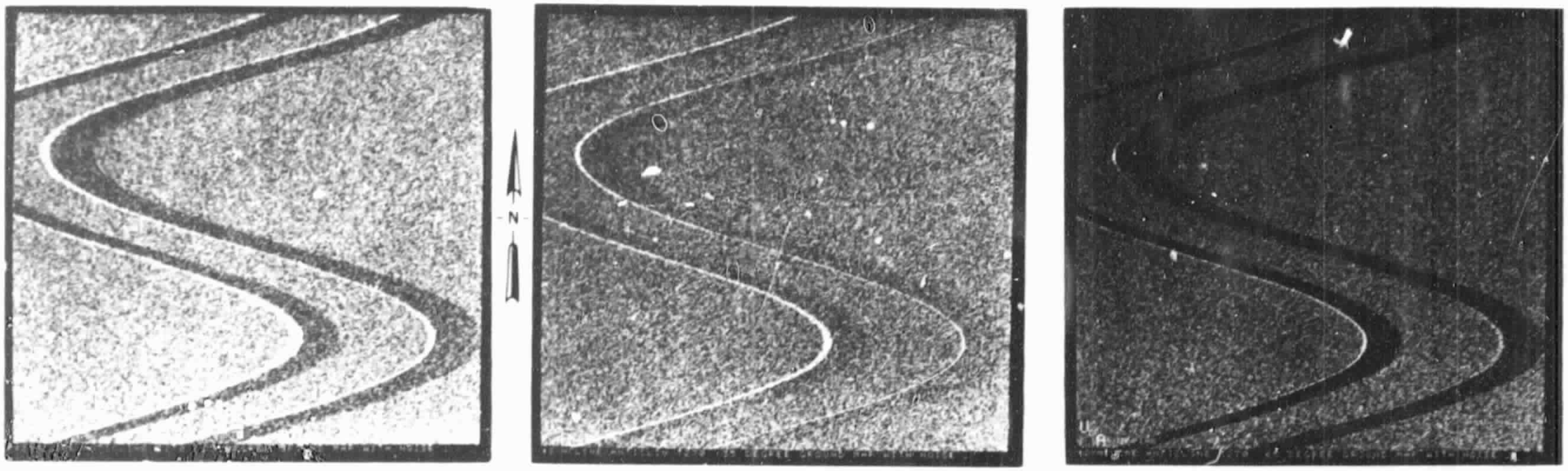


23° Angle of Incidence

35° Angle of Incidence

65° Angle of Incidence

Figure 4 Simulated Ground Range Radar Images of Anticline/Syncline Geologic Terrain Model (Look Direction is South)

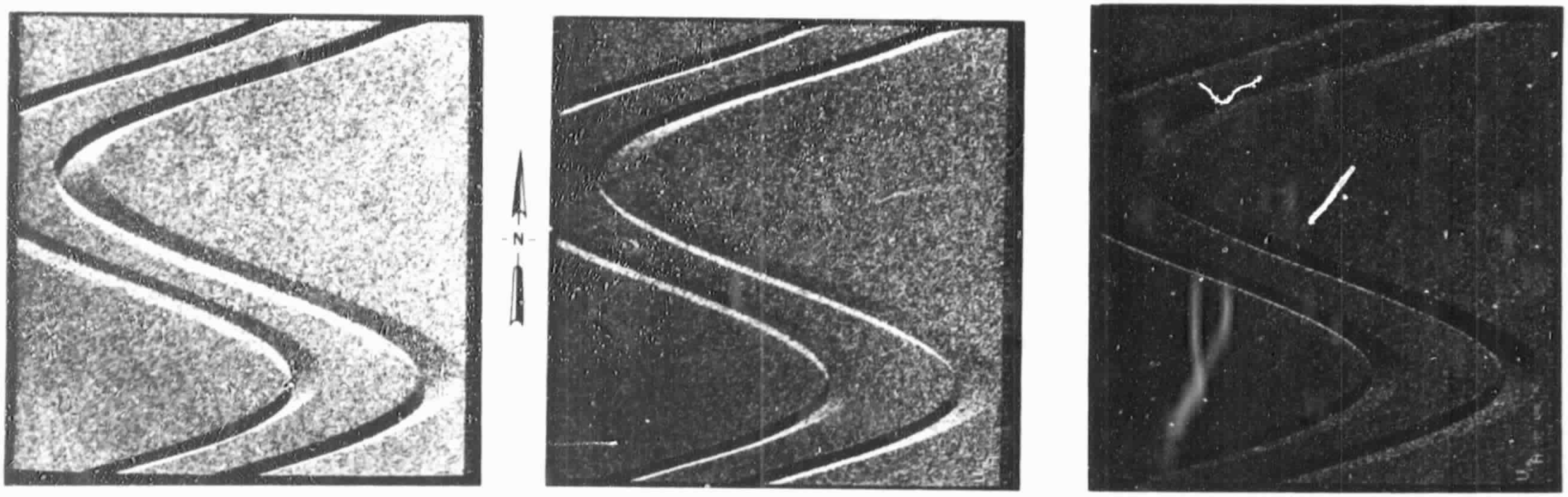


23° Angle of Incidence

35° Angle of Incidence

65° Angle of Incidence

Figure 5 Simulated Ground Range Radar Images of Anticline/Syncline Geologic Terrain Model (Look Direction is East)



23° Angle of Incidence

35° Angle of Incidence

65° Angle of Incidence

Figure 6 Simulated Ground Range Radar Images of Anticline/Syncline Geologic Terrain Model (Look Direction is North)

First, it is apparent from the four figures how different a common feature appears in radar imagery collected from varying look directions. As can be seen, the feature is more distinct and more easily interpreted when viewed from certain directions than for others. As a consequence, it is desirable to obtain multiple look directions for each scene to aid in unambiguous interpretation of subtle terrain features.

Second, it is clear that the foreslope to backslope contrast, clarity, and geometric fidelity of the feature are a strong function of angle of incidence. Note that in each case the geometric fidelity of the feature is best for the 65^{o} angle of incidence image, whereas the foreslope to backslope contrast and clarity are greatest for the 23^{o} image. Note also that the 35^{o} image is inferior in each case to either the 23^{o} or 65^{o} one.

Even for this simple, stark scene radar layover dominates the geometry of the 23^{o} images. If the scene were of mountainous terrain instead, the 23^{o} images would be largely uninterpretable. For subtly expressed features, however, the 23^{o} scenes are clearly portrayed and rapidly identified in spite of the severe layover characteristic at small incidence angles such as this. The conclusion is inescapable that the detail and fidelity portrayed in radar imagery of different kinds of terrain is dependent upon both the slope and relative relief of the terrain as well as the radar incidence angle and look direction. The usefulness of radar imagery for geologic applications is this dependent upon the application as well as the system parameters.

These simulated radar images illustrate enhanced feature interpretation at both small and large angles of incidence, and reduced feature interpretation in the mid-range angles. In general it would appear that for a variety of terrain types the best radar system is offered by one having at least two selectable angles or incidence; one small and one large. The next best compromise system is offered by one having the largest angle of incidence that can be attained within spacecraft limitations (i.e., one greater than 60°).

A.2 Layover and Shadowing

The Seasat Synthetic Aperture Radar (SAR) provided high quality, L-band, satellite radar data at $\Theta \simeq 20\text{-}26^{\circ}$. Analyses of these SAR data show an enhanced great sensitivity to slope in regions of low topographic relief [Ford 1980; Blom and Elachi 1981; Kaupp et. al., 1980, Saunders, et. al., 1979]. In regions of moderate to high relief, such low incidence angles result in geometric distortion, called layover (Figure 7A), that often severely compromises the usefulness of these images. This layover is clearly demonstrated in Figure 8A, a Seasat image (22° incidence angle) of the Santa Ynez mountains near Santa Barbara, California. Figure 8B is a SIR-A image of the same area with an intermediate

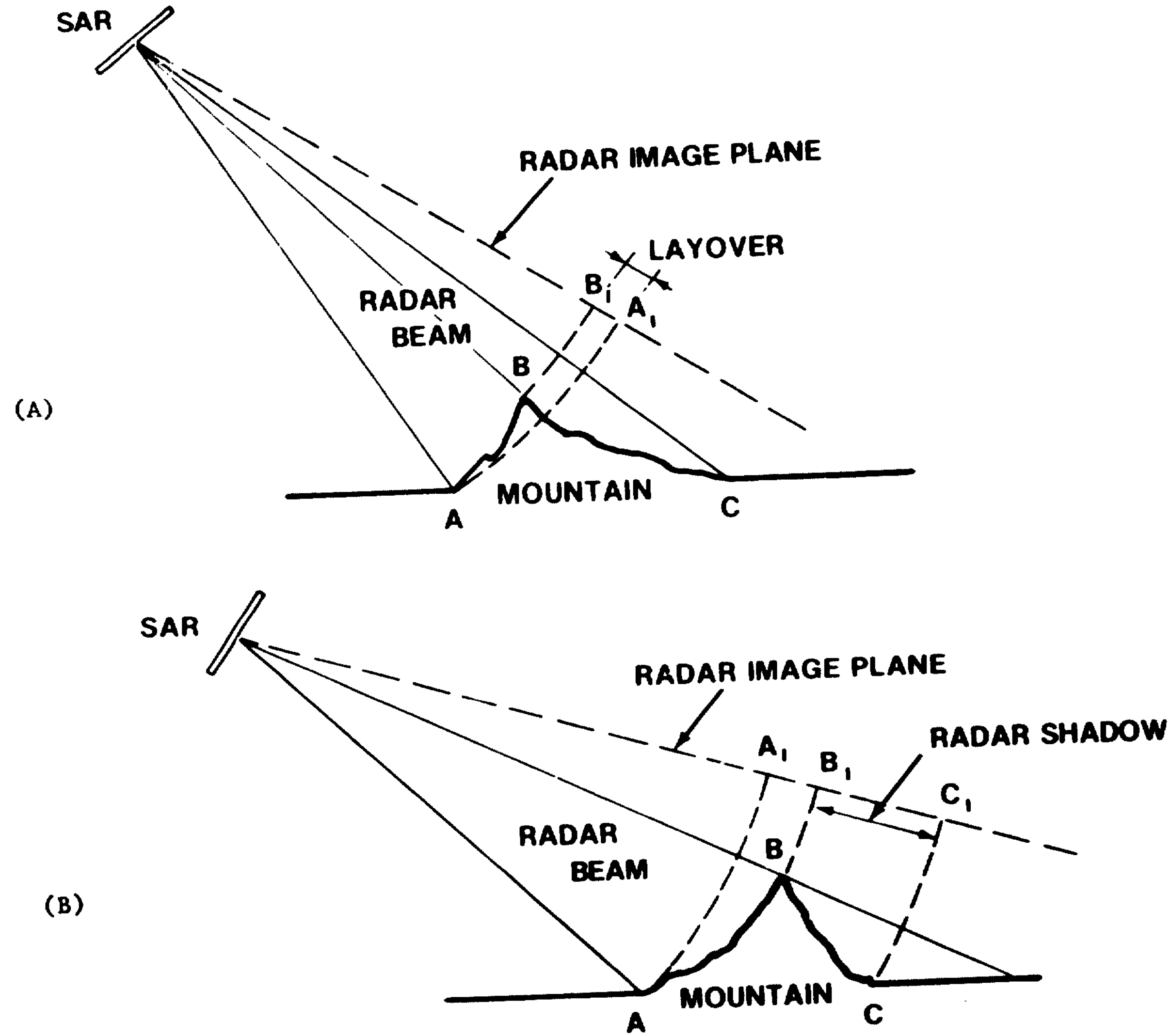


Fig. 7 (top) Geometry of layover in radar images
(bottom) Shadowing in radar images

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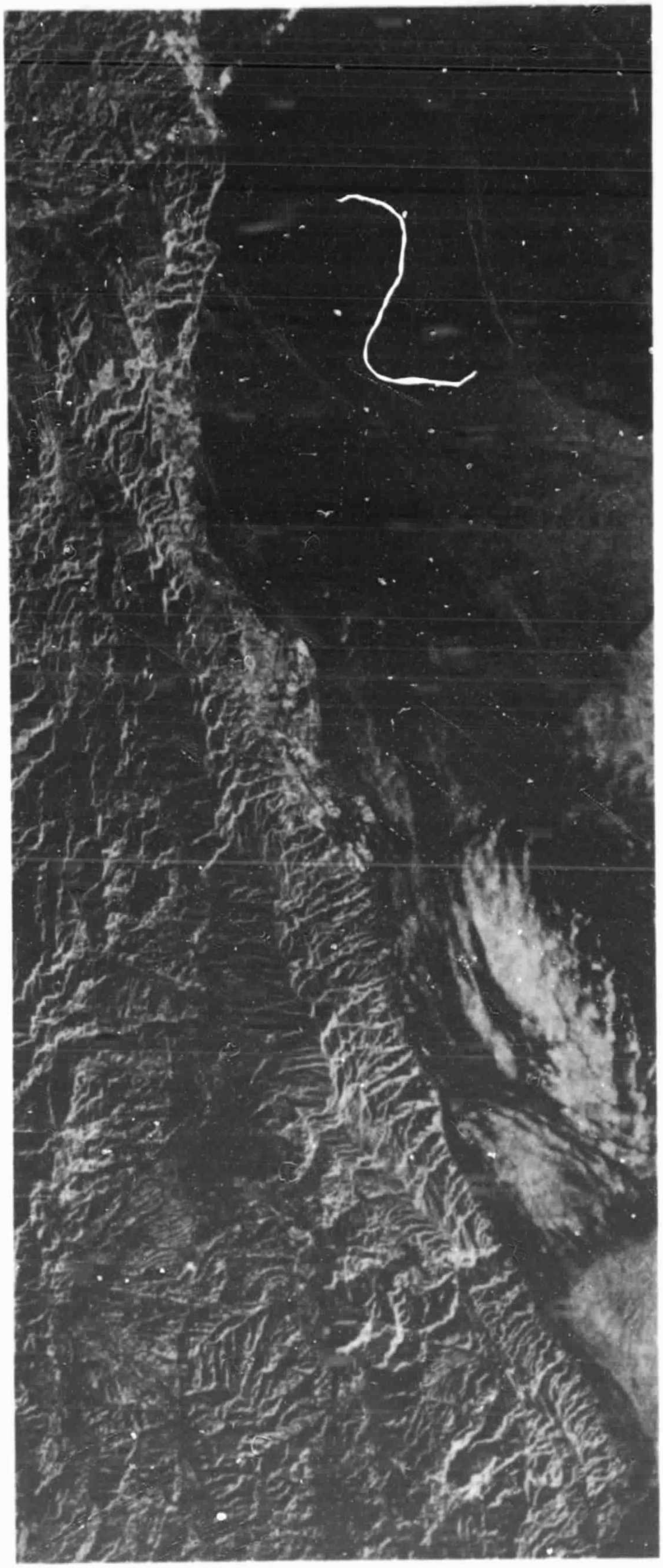


Fig. 8(a). Seasat mosaic image of California coast near Santa Barbara. Point Conception is at lower left and Ventura is at right center. Note severe layover and foldover in Santa Ynez mountain range images running along coast. The angle of incidence is 20°.

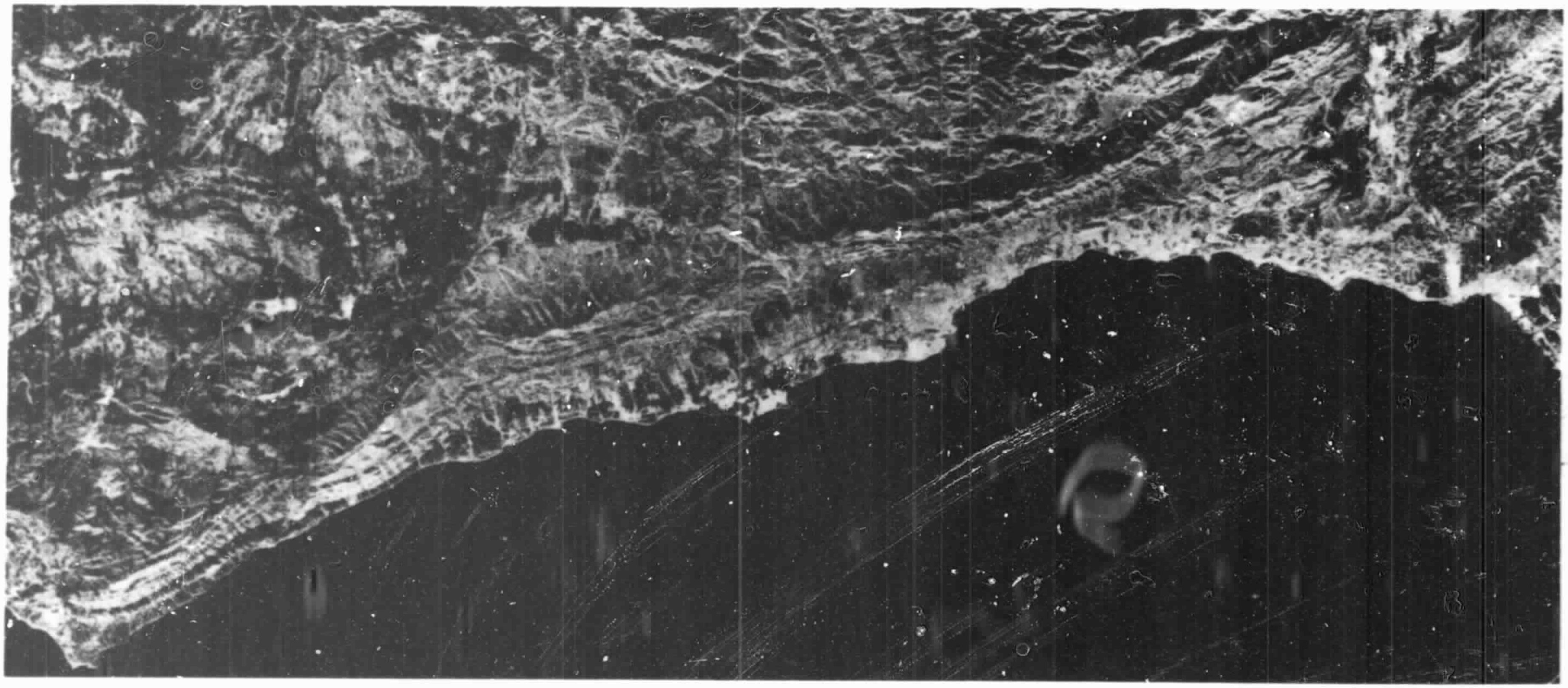


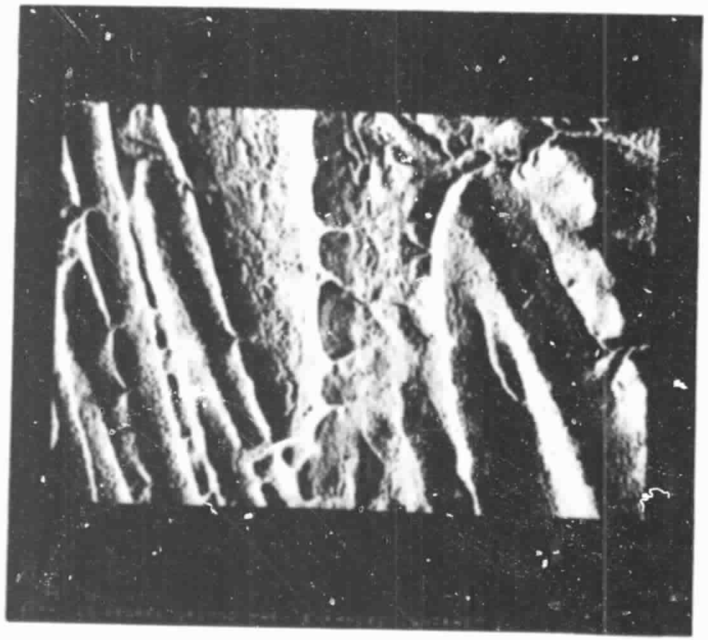
Fig. 8(b). SIR-A image of California coast near Santa Barbara. The angle of incidence is 47^0, resulting in much improved imagery of high relief Santa Ynez mountain range.

47° incidence angle, showing much reduced layover and foreshortening. If the incidence angle were very much greater than 65°, data would be lost in regions of high relief because of extensive shadowing (Figure 7B). The highest priority objective for FIREX is, therefore, to explore the enhanced sensitivity to topography at a look angle of 60°, corresponding to a ground incidence angle of about 65°. The satellite images would approximate prior aircraft images except that the view angle would be essentially constant across the scene, so that very much better geometric and radiometric control could be realized.

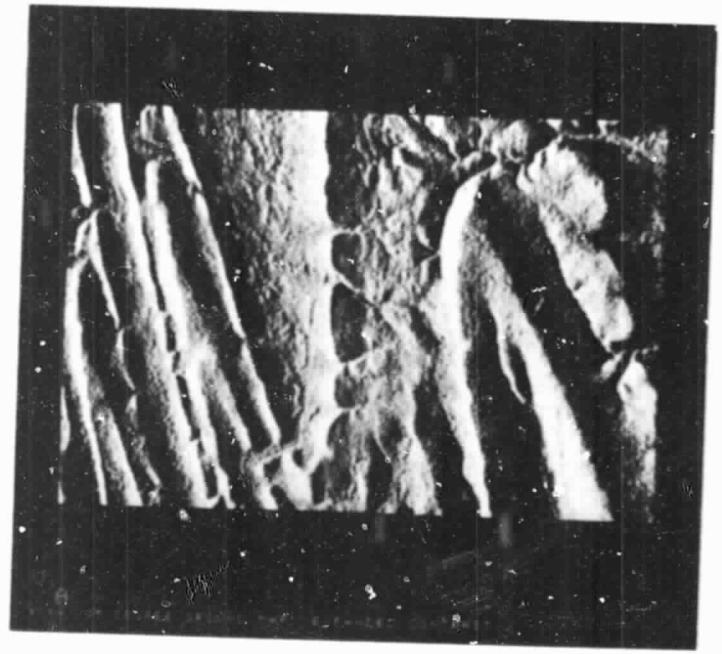
A.3 Radar Stereo

The high look angle experiment described above should be augmented by employing a second look angle of 30°-35° in order to permit studies of radar stereogrammetry. The combination of the 60° and 30° look angle data permits 30° convergence stereo—a powerful tool in geomorphology. It has been pointed out by Leberl [1979] that an approximate 30° convergence angle for radar images should be best for radar stereogrammetry.

Figures 9 and 10 (Kaupp, 1981) contain pairs of simulated radar stereo images created from the same digital elevation model. In both figures the stereo parallax is created in the image pair from the same scenario involving two looks at the ground from the same side but from different angles of incidence. In Figure 9 the angles of incidence are 35° and 65°, and in Figure 10 they are 23°

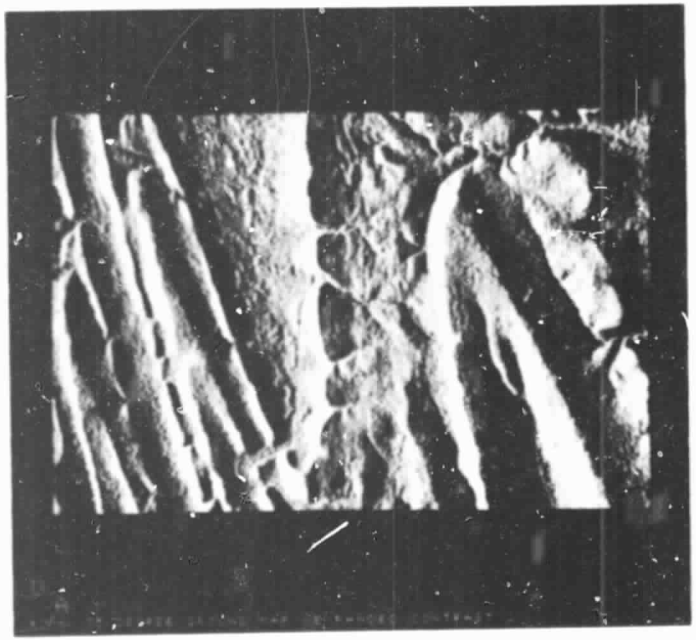


23° Angle of Incidence

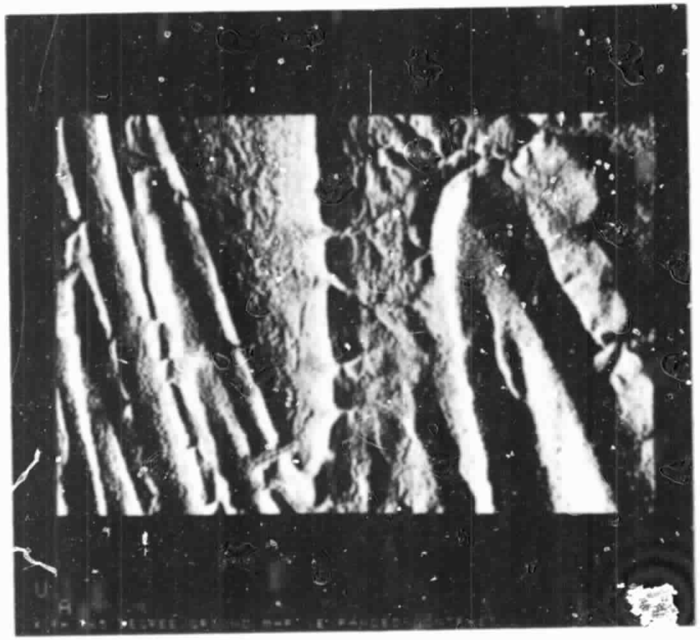


35° Angle of Incidence

Figure 9 Simulated Stereo Pair Ground Range Radar Images of Anticline/Syncline Geologic Terrain Model



35^{o} Angle of Incidence



65^{o} Angle of Incidence

Figure 10 Simulated Stereo Pair
Ground Range Radar
Images of Anticline/Syncline
Geologic Terrain Model

and 35^{o}, as noted. In both figures the radar look direction is from the left to the right.

As can be seen from the figures, the pictorial representation of each image and the parallax between each pair provides excellent stereoscopy. These figures vividly illustrate the value and utility of using computer-generated imagery for determining the optimum stereo radar scenario. Although these figures do not necessarily represent the optimum stereo scenario for radar, they do illustrate two sets of parameters for one candidate method. The optimum scenario and sets of parameters are yet to be determined.

Each image in the two figures has been especially processed to minimize distracting differences between stereo pairs without altering the parallax. Two obvious consequences of this processing is that fading noise has been suppressed and the total signal dynamic range has been mapped completely across the dynamic range of the film from black to white by equalizing the histograms of each scene. Such special processing was performed specifically to balance the contrast and, except for parallax, make each image of a pair look similar.

The combination of a 30^{o}-35^{o} look angle imagery with either low look angle or high look angle data will enable a detailed study of radar stereo using space-acquired data. Furthermore, the cumulative experience with high-quality, satellite radar at $\theta \simeq 20^{o}$

(Seasat), at $\theta \simeq 60^{o}$ (FIREX), and with stereo radar (FIREX) would enable a comprehensive evaluation of the geologic usefulness of satellite radar in the analysis of topography.

B. DISCRIMINATION AMONG GEOLOGIC TARGETS

The second specific objective for FIREX is to evaluate the use of backscatter radiances to discriminate among various geologic targets. Multispectral infrared reflectance data from Landsat and from aircraft sensors have been successfully used to discriminate among various soil and rock types [Goetz, Rowan, 1981] and among geobotanical anomalies [Taranik, Sheehan and Carter, 1978]. Infrared reflectance varies with soil, with rock, or with vegetation chemistry. In contrast, radar backscatter from vegetated surfaces varies with surface roughness, with leaf geometry and canopy morphology, or with moisture content. Therefore, the combination of infrared and microwave data should provide better geologic discrimination than infrared data provide alone.

B.1 Minimizing Effect of Topography

The corollary to increased sensitivity to topography at incidence angles less than 25^{o} or greater than 60^{o} is diminished sensitivity to topography at $25^{o} < \theta < 60^{o}$. Where the objective is spectral discrimination among targets using a combination of infrared and microwave reflectance data, confusion caused by topography is undesirable. Data at 30^{o}-40^{o} look angles should be preferable for multispectral studies to the 20^{o} Seasat data, or to the 60^{o} look angle data proposed under objective (1).

B.2 The Value of Like and Cross Polarized Radar Images

It is strongly recommended that FIREX include both a like (HH) and cross (HV) polarized imaging capability at the intermediate (30^{o}-35^{o}) view angle. The need for this is based upon both past experience with dual-polarized aircraft radar imagery and also upon the theoretical predictions of scattering theory (e.g., Lang, 1980) and field measurements with truck and aircraft scatterometers which show a very strong dependence of vegetation type on the ratio of like- to cross-polarized data at C-band and higher (Paris, 1981).

As previously mentioned, the image format of spaceborne SAR data provides a unique capability in assessing feature dependent radar backscatter signatures. Moreover, previously acquired aircraft radar imagery clearly demonstrates the existence of an authentic depolarization phenomena in radar backscatter.

The existence of feature dependent depolarization is illustrated in Figure 11, a pair of radar images of the Pisgah Crater, California, area recorded by APQ-97 Ka-band side-looking airborne radar (SLAR) [Skolnik, 1970] system. The Westinghouse SLAR used to obtain this image transmitted a horizontally polarized signal.[1] Both the like and cross polarized imagery were recorded. Two

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[1] Horizontal polarization: linear polarization in which the electric field vector lies perpendicular to the plane of incidence.
Vertical polarization: linear polarization in which the electric field vector lies parallel to the plane of incidence.

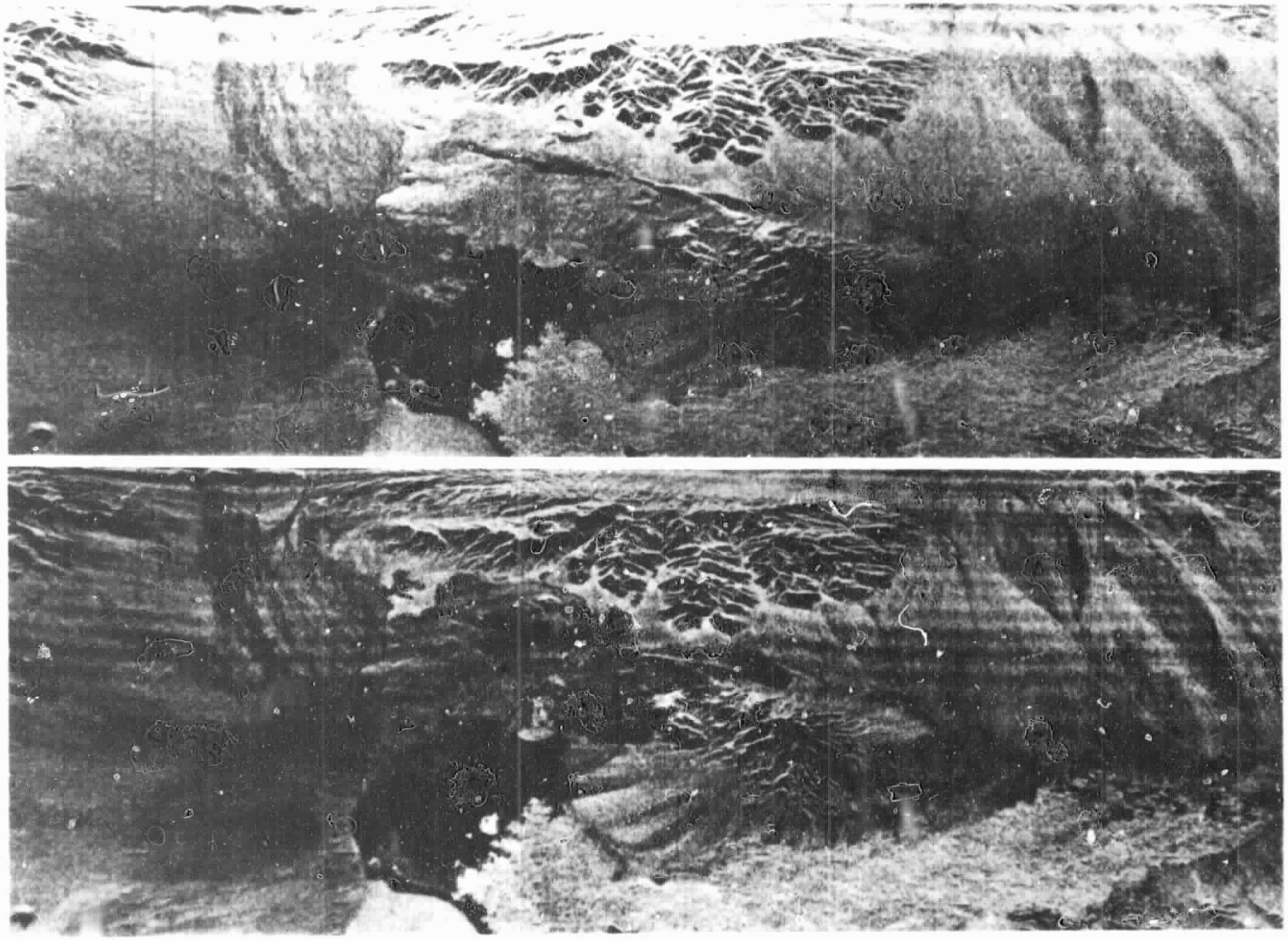

Fig. 11. Ka-band SLAR images of the Pisgah Crater - Lavic Lake area
(upper image) - horizontal transmit, horizontal receive
(lower image) - horizontal transmit, vertical receive

separate lava flows have contrast definition on the cross polarized return; however, on the like polarized imagery these contrasts are not apparent.

Figure 12 is a dual polarized K-band image of the southeastern part of the Twin Butte, Arizona, quadrangle. The cross polarized return clearly shows two outcrops of pyroxene rhyodacite [Dellwig, et. al., 1968a]. These outcrops appear as conspicuous areas of low return on the cross polarized image. The outcrops are not apparent on the like polarized image, nor on aerial photographs. A subsequent field check failed to show unique differences in topographic structure. The surface structure of the outcropped area was very similar to the surrounding regions. However, the composition of each was very different.

Additional indications of cross polarized radar return can be seen from the imagery in Figure 13. These K-band dual-polarized images from the Mono Craters volcanic area in northern California have been analyzed for differences in age of lava flows. Throughout this area of recent volcanoes, the contrast between lava and flanking ash and cindersheds is similar in the VV and VH radar returns. However, the return from the crater (A) and the lava domes (B, C, D,) and the coulee (E, F) are relatively lower in the VH image than in the VV image. All the areas with diminished return on the cross polarized imagery are devoid of vegetation. Conversely, all the areas which show little difference in the imagery are areas of older flows and are covered with soil and

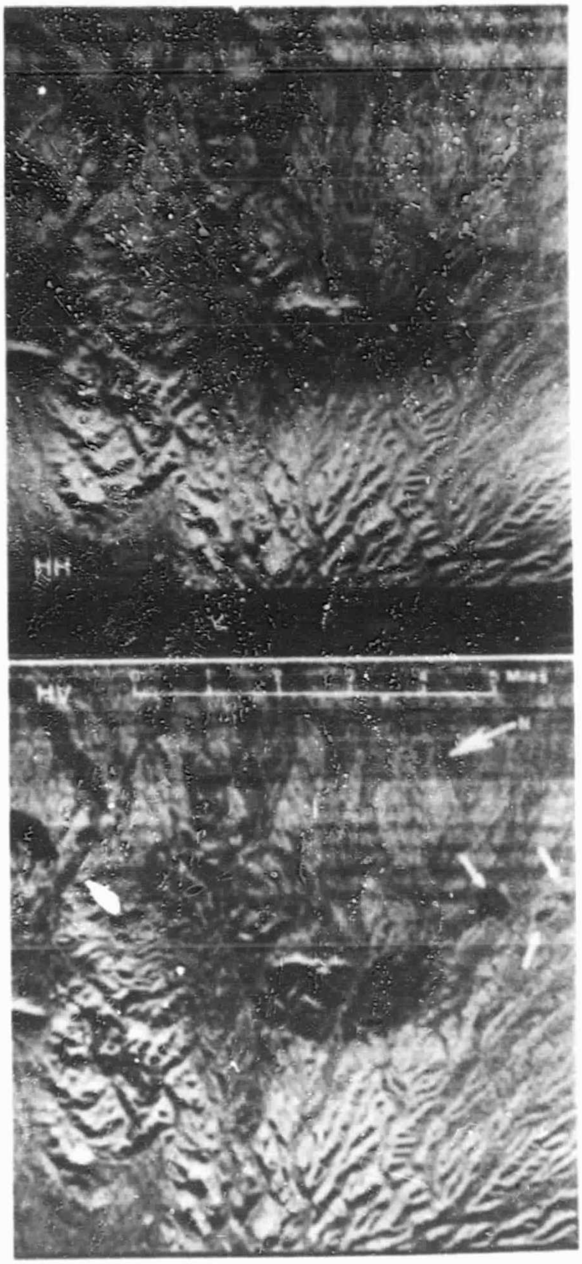

Fig. 12. HH-polarized (upper) and HV-polarized (lower) imagery of Twin Buttes, Arizona. The dark area (arrows in lower image) of rhyodacite bedrock was not identified prior to imaging by radar.

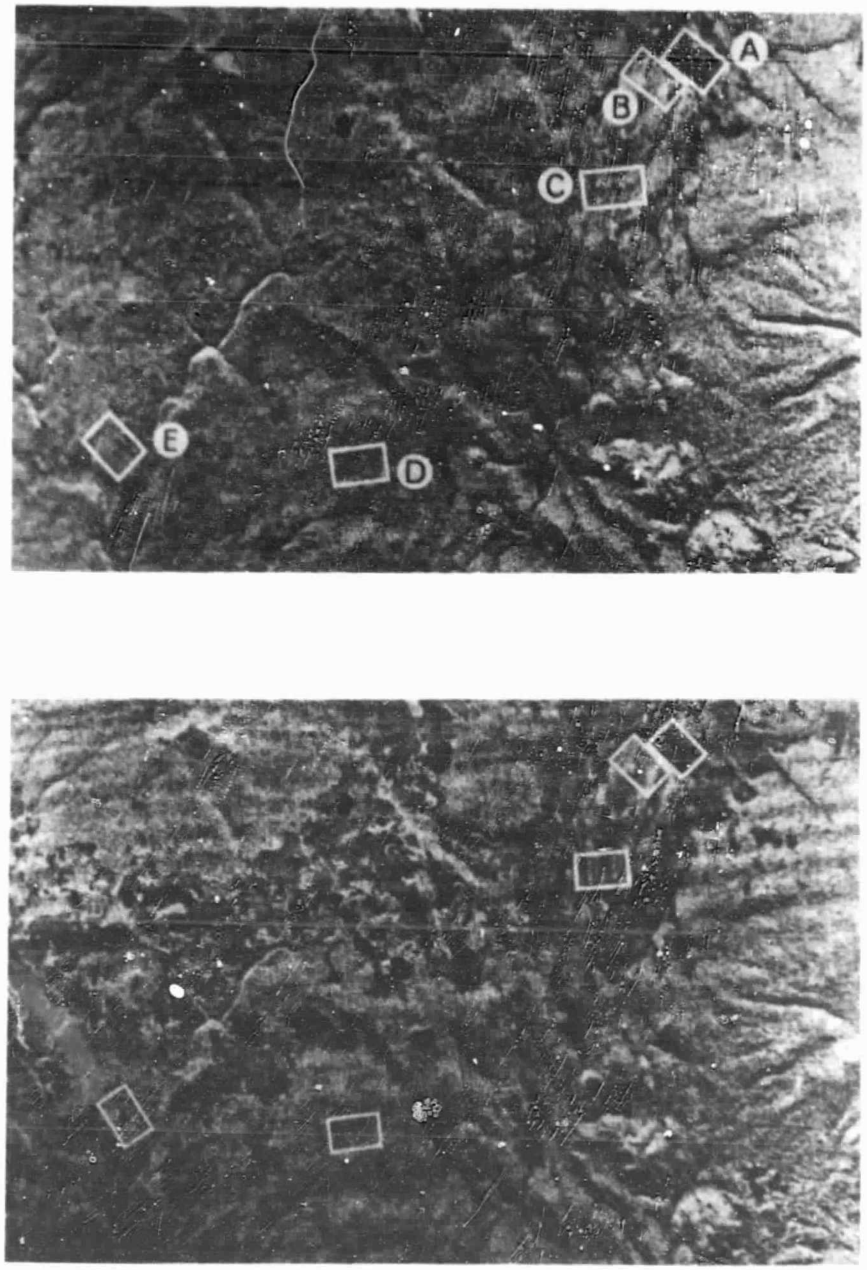

Fig. 13. Mono Crater, California dual-polarized radar images with HH-polarized (upper) and HV-polarized (lower). Unique areas of flow rock (A-E) can be delineated.

vegetation. The surface of the older lavas is relatively smooth, compared to the rough terrain characteristic of younger lavas. Differences in the radar return appear to be a function of the differences in the terrain character of these areas. Roughness, vegetation and perhaps age are of primary importance [Dellwig, et. al., 1968b].

V. SATELLITE REQUIREMENTS

The task of this Study Team has been to identify the mission requirements for applications in Non-Renewable Resources, and, where these requirements differ from the C-band baseline system, justify the required change. A set of five progressively more ambitious mission configurations (A-E, Table 2) has been developed. The list is prioritized in the sense that Configuration B represents an augmentation of the capabilities of Configuration A, and that Configuration C represents an augmentation of Configuration B, etc. The following requirements are common to all configurations:

(i) Resolution: 30m x 30m (6-8 looks)

There is no single spatial resolution that is ideal for all geologic applications. Nonetheless, there have been several studies (e.g., [Snowmass Radar Geology Workshop, 1980]) recommending 30m as a reasonable compromise between the interpreter's desire for high resolution and wide swath, and today's cost per amount of data processed. Furthermore, many

TABLE 2

SUMMARY OF MISSION REQUIREMENTS

General

Resolution: 30m x 30m

Relative Calibration: 1dB

Sensitivity (noise equivalent σ^o): -35dB

Mode Isolation: 25 dB

Swath Width: 150 km (1 channel)

75 km (2 channels)

50 km (3 channels)

Configuration A:

C-band, HH-polarized, $\theta = 60^o-65^o$ (high look angle)

Configuration B:

Configuration A plus C-band, HH-polarized, $\theta = 30^o-35^o$ (intermediate look angle)

Configuration C:

Configuration B plus C-band, HV- and HH-polarized, $\theta = 30^o-35^o$ (int. look angle)

Configuration D:

Configuration C plus L-band, HH-polarized, $\theta = 15^o-20^o$ (low look angle)

Configuration E:

Configuration D Plus L-band, HH-polarized, $\theta = 30^o-35^o$

anticipated geologic studies involve merging FIREX data with multispectral infrared reflectance data. The state-of-the-art satellite multispectral system during the 1980's will be the Thematic Mapper (TM) whose resolution is 30m. FIREX data should be made compatible with TM data. Therefore, we endorse the 30m x 30m resolution stipulated for the baseline mission as the resolution requirement for all four of our mission configurations.

(ii) <u>Spatial registration to about 30m and relative radiance calibration to 1 dB</u>.

This registration is commensurate with the requested resolution and the radiance calibration is based upon the need to relate small changes in radar backscatter to soil moisture and roughness effects.

(iii) <u>Sensitivity</u>: - 35 dB

<u>Mode Isolation</u>: 25 dB

The cross polarized backscatter from some terrain is below -30dB. This figure would become increasingly critical at longer wavelengths where an increasing number of pixels in a typical scene can be expected to have cross polarized returns below -30 dB.

The cross polarized return is typically 10-15 dB below the like polarized return. Isolation of 25 dB between modes would effectively prevent the like return from polluting the cross-polarized channel.

(iv) <u>Swath width</u>: 150 km (1 channel)

75 km (2 channels)

50 km (3 channels)

Satellite remote sensing is particularly well suited to regional geologic studies [MacDonald, 1969; Wing, 1971; Correa, 1980]. Regional studies may include much of a structural province such as the Piedmont, the Valley and Ridge, or the Eastern Coastal Plain. For such regional studies, the radar images must be combined in mosaics. While there is no technical limit to the number of scenes in a mosaic, it is very difficult to suture more than a very few images in such a way that geometry is preserved and junctures are concealed. The 150 km swath in the baseline mission offers a reasonable compromise between the desire for wide swaths and the cost of managing high data rates.

Computationally intensive image enhancement processes, such as pixel by pixel registration of multiple data sets, ratioing, stretching, or rotation of axes in frequency space are not amenable to regional investigations because of the high cost of the computation. These processing techniques are appropriate for a single scene or for a subset of a scene. Multimode radar is intended for these limited area, computationally intensive investigations, so that it is reasonable to use the multimode capability at the expense of swath width. Configuration C specifies both like and cross polarized C-band capability. When the system is operated in the exclusively like polarized mode, the requirement is a 150 km swath. When the system operates in the like and cross polarized mode, the swath is reduced to 75 km. Similarly, configuration D, when operated in L-band like and C-band like and crossed polarized modes, has a swath requirement of 50 km.

Configuration A: C-band HH polarized, $\Theta = 60^{\circ}$–65°.

The simplest meaningful satellite experiment is the C-band baseline mission. However, a look angle of 60° is a more appropriate initial configuration for geological applications than the baseline look angle of 30° since Seasat used a low look angle and SIR-A used an intermediate angle. A look angle of 60° at orbital altitude corresponds to an incidence angle at the Earth's surface of about 65°. Wavelength and polarization at the 60° look angle are not critical. We specify C-band, HH-polarized simply because that was the baseline mission given.

The Shuttle Imaging Radar Experiment-A (SIR-A) mission was flown November 12-14, 1981, on STS-2. SIR-A optically recorded L-band, HH-polarized data covering about 10 million sq.km. at a 47° incidence angle during its 2-day mission. This data will provide valuable experience with relatively high incidence angle satellite radar data. The benefits of increasing Θ to 60° (incidence angle $\simeq 65^{\circ}$), coupled with digital image processing, repeat coverage during several seasons, and the possibility of gaining experience with C-band justify Configuration A. However, because FIREX postdates SIR-A by several years, Configurations B-D, which are augmentations of Configuration A, became far more meaningful experiments. Our scientific requirements demand that we move beyond the single frequency, single mode radar.

Configuration B: Capabilities of Configuration A plus a second look angle (30°-35°)

As previously noted, sensitivity to topography has been the primary geologic justification for airborne radar. This sensitivity would be further explored through an experiment with stereo radar. Configuration A augmented by a second incidence angle, $\Theta = 30^{\circ}$, would permit 30° convergence stereo. Stereo capability is highly desirable in the FIREX experiment, to enable an assessment of the utility of spaceborne stereo radar for topographic mapping.

Configuration C: Capabilities of Configuration B plus cross-polarized, C-band radar data at $\Theta = 30^{\circ}$-35°

The second set of experiments possible with Configuration B involved combining infrared and microwave reflectance data for multispectral discrimination among natural targets. The recommendation under objective (2) in Section IV was that FIREX include a like and cross polarized experiment at an intermediate look angle for the purpose of improved mapping of vegetated terrain. Configuration C would be a fundamentally new experiment, making use of like and cross-polarized intermediate look angle imagery.

The Study Team strongly recommends that FIREX have at least the capabilities specified in Configurations A, B, C, and D.

Configuration D: Capabilities of Configuration C plus HH-polarized C-Band radar data at $\Theta = 15^\circ$-20°

Radar backscatter exhibits maximum sensitivity to subtle topographic expression in the 15°-20° range of look angles. This configuration is consistent with the need to conduct geologic mapping experiments in regions of low relief. It is complementary to Configuration A, which is ideal for geologic mapping in mountainous regions of high relief.

Configuration E: Capabilities of Configuration C plus HH-polarized, L-band radar at $\Theta = 30^\circ$

Many additional significant experiments become possible if a second frequency were added to FIREX. Empirical and theoretical considerations suggest the optimum frequency separation is a factor of 3 or 4. That is, if C-band is the prime system, L-band becomes an appropriate additional frequency. The objective is discrimination among geologic targets based upon the spectral characteristics of the radar backscatter. Confusion caused by variations in the scattering process or by slope should be minimized. Therefore, the second system (L-band) should be HH-polarized, and it should have the intermediate look angle ($\Theta = 30^\circ$) of the prime system. Furthermore, satellite L-band at $\Theta = 30^\circ$ will complement L-band Seasat data ($\simeq 20^\circ$) and SIR-A data ($\simeq 47^\circ$).

Alternatives

The progression of Configurations A-E are self consistent and define progressively more meaningful experiments. However, the primary reason for specifying a C-band system was the original baseline designation of a C-band SAR. A similar set of configurations based upon an L-band system would be equally acceptable. Table 3 is a summary of the Study Team's position with respect to C-band and L-band. The consequence of building upon L-band would be the following progression:

Alternative A: L-band, HH-polarized, $\Theta = 60^\circ$-65°

Alternative B: Alternative A plus L-band, HH-polarized, $\Theta = 30^\circ$-35°

Alternative C: Alternative B plus L-band, HV- as well as HH-polarized $\Theta = 30^\circ$-35°

Alternative D: Alternative C plus L-band, HH, 15°-20°

Alternative E: Alternative C plus C-band, HH-polarized, 30°

TABLE 3

SUMMARY OF ALTERNATIVES WITHOUT REGARD TO BASELINE MISSION

RESEARCH OBJECTIVES	REVISIT TIME	RESOL./ # LOOKS	LOOK ANGLE P=PRIME A=ACCEPT 15^o 25^o 35^o 45^o 55^o	FREQUENCY/POLARIZ. P=PRIME A=ACCEPT L_{vv} L_{hh} L_{hv} C_{vv} C_{hh} C_{hv}	IMPROVEMENT H=HI, M=MED, L-LO L+C	BOTH POL. R=RESEARCH ISSUE	IS SAR PRIME OR COMPL.	REL. CAL. REQ.	REGISTRATION ACCURACY
Sensitivity to Topography									
Arid & Semi-Arid	once	30/6-8	A - - - 60^o	any one P P - P P -	-	-	P	1 dB	30m
Vegetated	seasonal	30/6-8	A - - - 60^o	any one P P - P P -	-	-	P	1 dB	30m
Sensitivity to Roughness & Vol. Scatt.									
Arid & Semi Arid	once	30/6-8	A A P A -	either one - P - - P -	H^r	H^r	C	1 dB	30m
Vegetated	seasonal	30/6-8	A A P A -	either pair - P P - P P	M^r	H^r	C	1 dB	30m
Sensitivity to Moisture									
Arid & Semi-	several times each season	30/6-8	A A P A -	- A - - P -	M	H	P	1 dB	30m

VI. AIRCRAFT REQUIREMENTS

FIREX would not likely be launched before the late 1980's. While enough is known today to specify, with some confidence, most of the system parameters for FIREX, few of the necessary data processing algorithms exist, nor have many experimenters had experience beyond like polarized, optically processed aircraft X-band and L-band or digitally processed L-band data. A vigorous aircraft program to provide a set of calibrated multi-frequency radar images for a set of test sites would permit experimenters to improve processing techniques, refine theoretical models, and develop experiment controls such as field sampling protocols for FIREX. Such an aircraft program would have the further benefit of stimulating a broad user community to anticipate the information content inherent in FIREX.

The aircraft program would be comprised of a series of local field experiments, and data products would be standardized. An extremely useful set would include HH- and HV-polarized, X-, C-, and L-band data at intermediate incidence angles ($25^\circ < \theta < 45^\circ$); and HH-polarized X-, C-, and L-band data at high incidence angles ($\geq 55^\circ$). These data sets would be acquired seasonally where appropriate. The value of these data would be greatly enhanced if considerable care is exercised in maintaining geometric and radiometric control. Furthermore, the only realistic means for achieving an adequate data set control is through the use of digital processing for aircraft SAR images.

The Study Team has chosen five arid and semi-arid test sites and three vegetated test sites, shown at locations N1-N8 on the map of Figure 14.

(Test site locations for the Renewable Resources Study Team experiments are also shown on this map.)

1.0 Arid and Semi-Arid Sites

Arid and semi-arid sites show little seasonal variation so that single coverage is adequate. A prioritized list of these sites follows:

1.1 Death Valley, California

This area has a considerable variety of surface roughness units which correspond to a wide range of backscatter cross sections. The majority of these units have been mapped in detail by G. Schaber and his colleagues at USGS and calibrated backscatter cross sections at four frequencies have been acquired with the NASA JSC airborne scatterometer. Thus, this area is the best test site to conduct SAR calibration experiments and to determine the best combinations of radar data to classify surface roughness units [Daily, et. al., 1978].

Figure 15 is a map of the Death Valley site.

1.2 Patrick Draw, Wyoming

Patrick Draw has been used by NASA and the mineral industry since 1978 as a test site to evaluate remote sensing techniques as part

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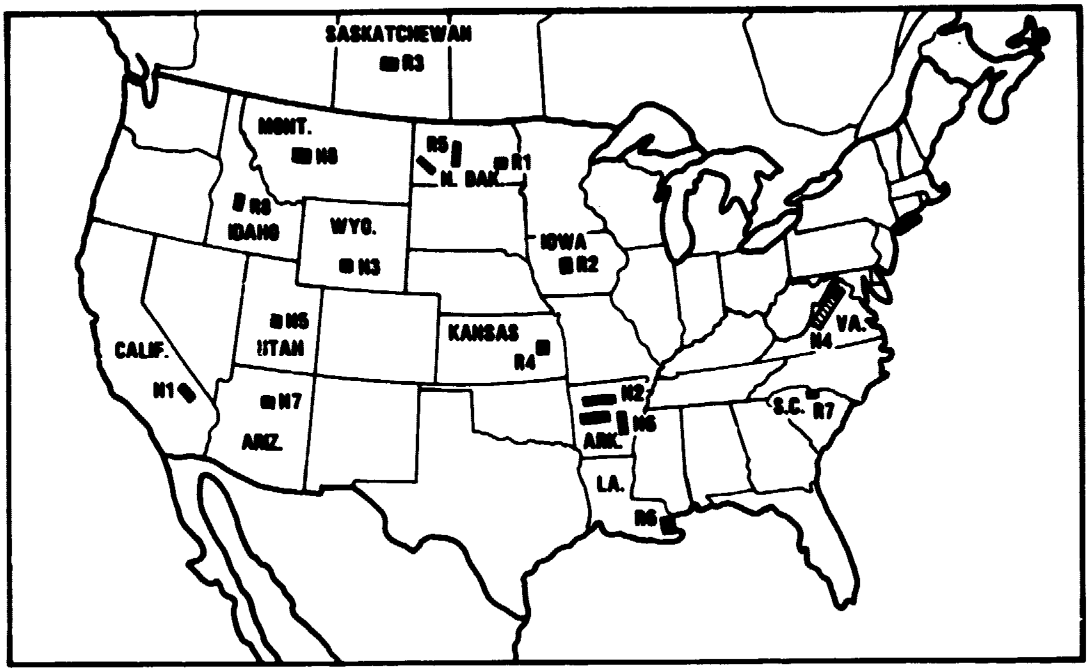

Site No.		Location	Renew	Non-Renew	Comments
prioritized	R1	Cass Co., N.D.	X		AgRISTARS Supersites — Crop
	R2	Webster Co., Iowa	X		separability and condition
	R3	Saskatchewan	X		U.S./Canadian ag. site
	R4	Eudora, Kansas	X		Soil moisture
	R5	Minot, N. Dakota	X		Snow
	R6	Mississippi/Louisiana	X	X	Wetlands/Coastal/Geobotany
	R7	Kershaw Co., S. Carolina	X		Forestry
	R8	Idaho	X		Forestry
prioritized	N1	Death Valley, California		X	Arid site
	N2	Arkansas		X	Geobotany, topographic test site
	N3	Patrick Draw, Wyoming		X	GEOSAT test site
	N4	Virginia		X	Geobotanical test site
	N5	San Rafael Swell, Utah		X	Semi-arid site
	N6	Little Rock, Arkansas		X	Gravel bars, wetlands test sites
	N7	Coconino Plateau, Arizona		X	Semi-arid site
	N8	Montana		X	USGS CUSMAP Project

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Fig. 14. Land Resource Test Sites, FIREX Mission Requirements Study

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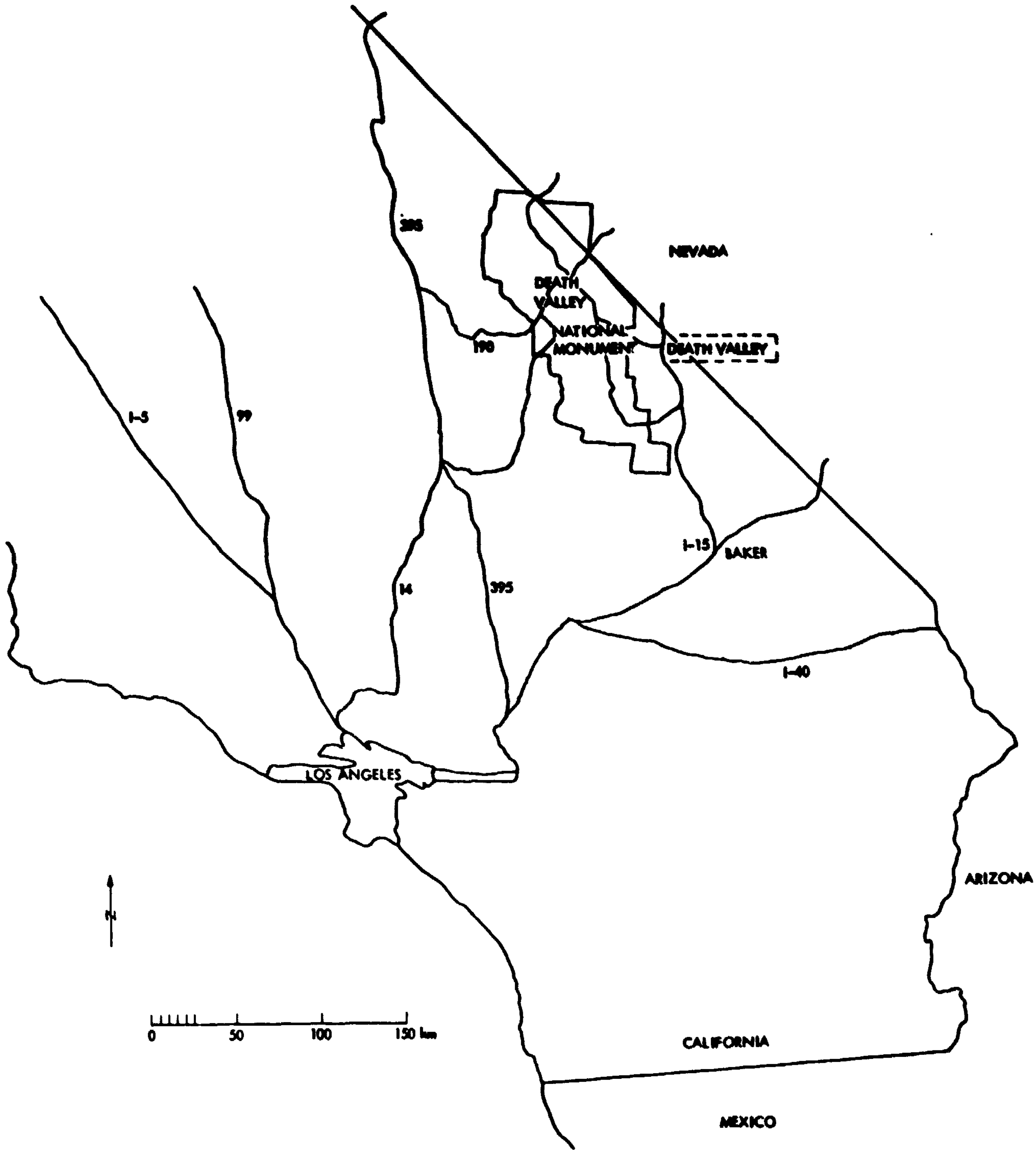

Figure 15. Location map of Death Valley, California.

of a successful Geosat/NASA program. Some of the reasons for the selection of Patrick Draw are listed below:

a. surface and subsurface geology are reasonably well known;

b. test site includes an oil field classified as a stratigraphic trap and the geological setting is typical of much of the Rocky Mountain region;

c. location is remote and terrain surface has had limited cultural disturbance;

d. vegetation is sparse and shows little seasonal variation; and

e. extensive remote sensing data acquisition and analysis has been directed towards the site. All of this data is readily available to our program.

The objectives of an experimental program at the Patrick Draw site are listed below:

a. Study of radar backscatter characteristics of geological units present in test site.

b. Evaluation of the potential of SAR as a geological mapping tool.

c. Evaluation of the significance of reduced vegetation cover in lithologic identification in radar images.

d. Evaluation of the significance of look direction polarization, incidence angle, and multispectral radar systems in this geological setting.

e. Evaluation of the usefulness of radar backscatter radiance combined with visible/infrared reflectance to discriminate geological features.

Figure 16 is a map of the Patrick Draw test site.

1.3 San Rafael Swell, Utah

Earlier work was conducted on classifying the geologic units in this area by using Seasat SAR, Landsat and HCMM data. [Blom, Abrams, and Conrad, 1981]. The multispectral aircraft data will be used to further analyze the synergism of multiple frequency and multipolarization radar data in conjunction with multispectral Landsat data for separating lithologic units. Figure 17 provides a location map and diagram of a stratigraphic column of exposed rocks for the San Rafael Swell site [Conel, Abrams and Goetz, 1978].

1.4 Coconino Plateau, Arizona

An extensive set of radar backscatter data over the Coconino Plateau has been collected by G. Schaber and his associates (USGS, Flagstaff). This includes airborne scatterometer data at L-Band, C-Band and Ku-band, airborne SAR imagery at L-Band and X-Band and Seasat L-Band SAR imagery. Thus, this well-studied area is a good

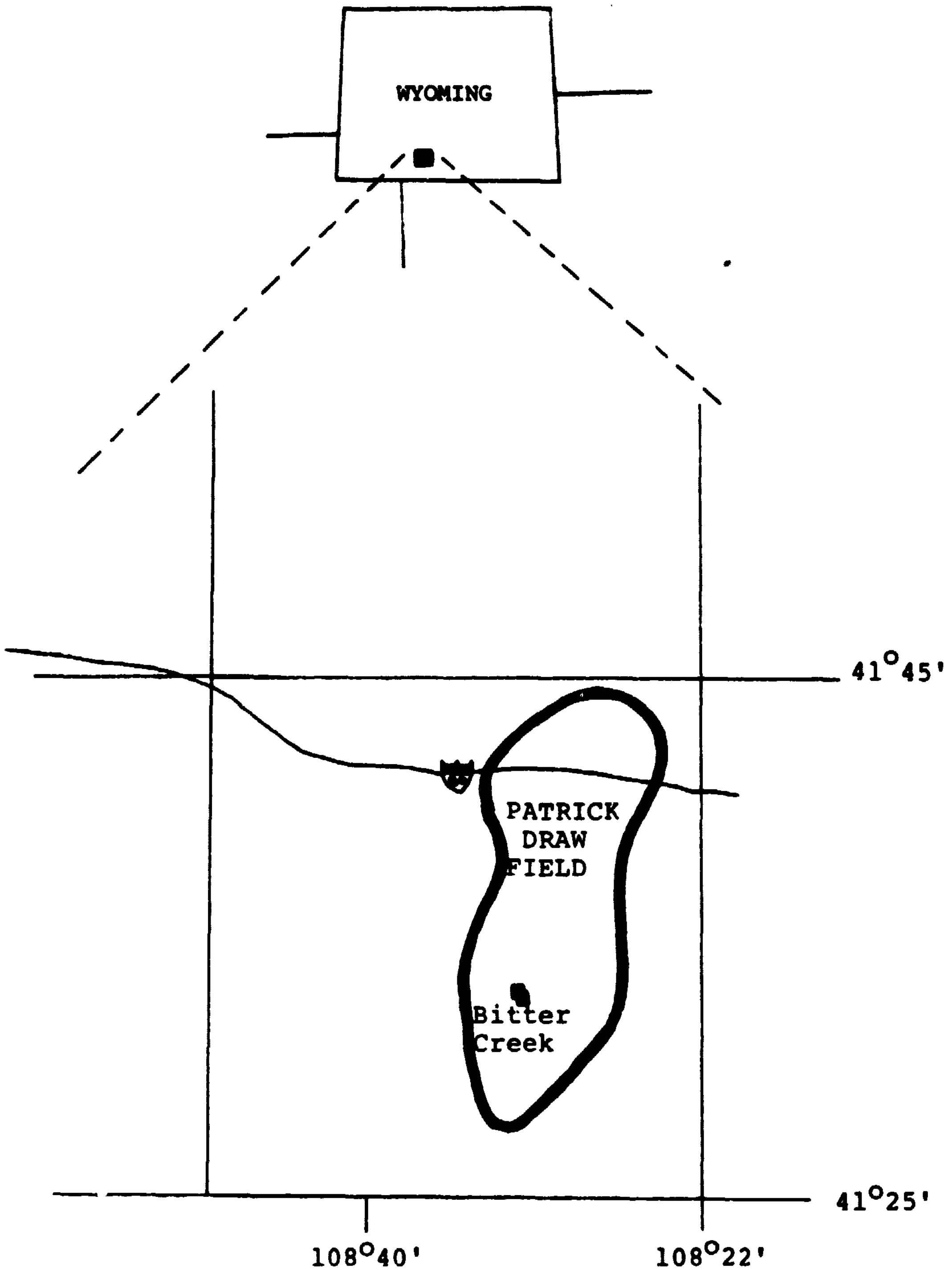

Fig. 16. Location of Patrick Draw (Sweetwater County), Wyoming. GEOSAT Test Site.

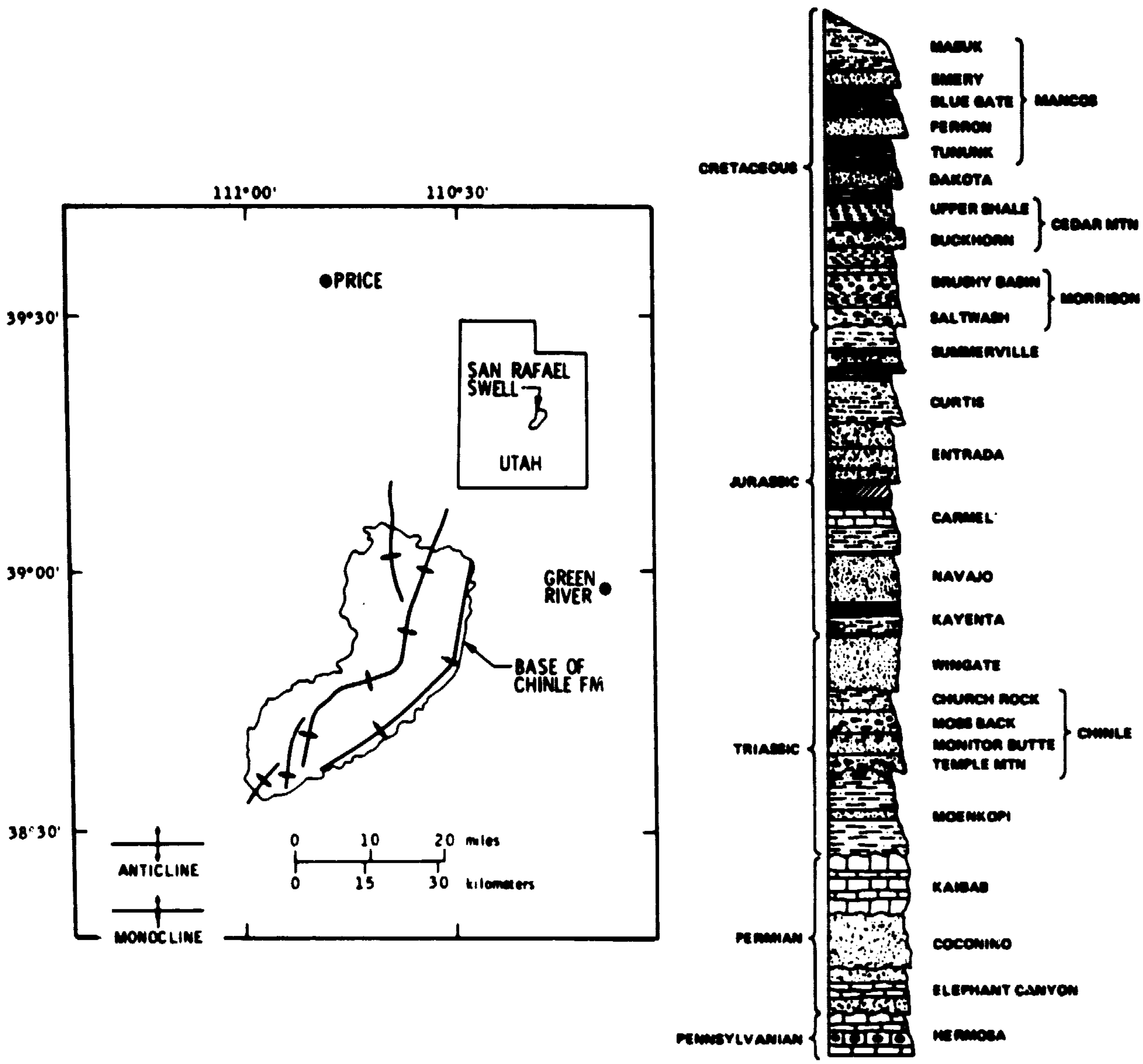

Figure 17. Location map and stratigraphic column of exposed rocks for the San Rafael Swell, Utah. After Conel, Abrams and Goetz, 1978, p. 3-2, 3.

candidate site for further investigations under the FIREX program. Figure 18 shows the proposed $1^{\circ} \times 2^{\circ}$ rectangle, extending from 35° to 37° north latitude and 110°-114° west longitude.

1.5 Beaverhead County, Montana

This site is used by the USGS CUSMAP project for its Montana placer study. Figure 19 is a map of this site.

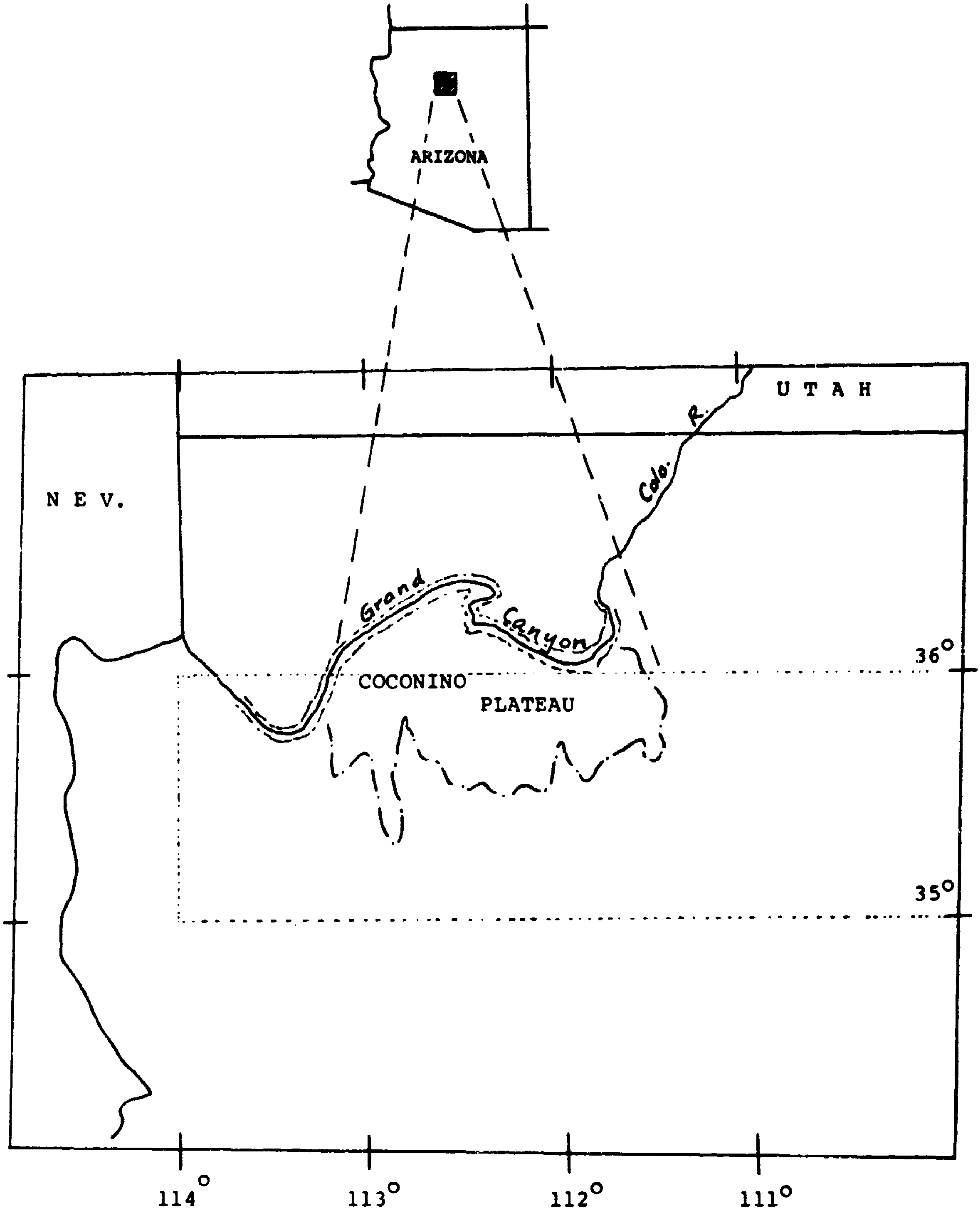

Fig. 18. Location map of Coconino Plateau, Arizona

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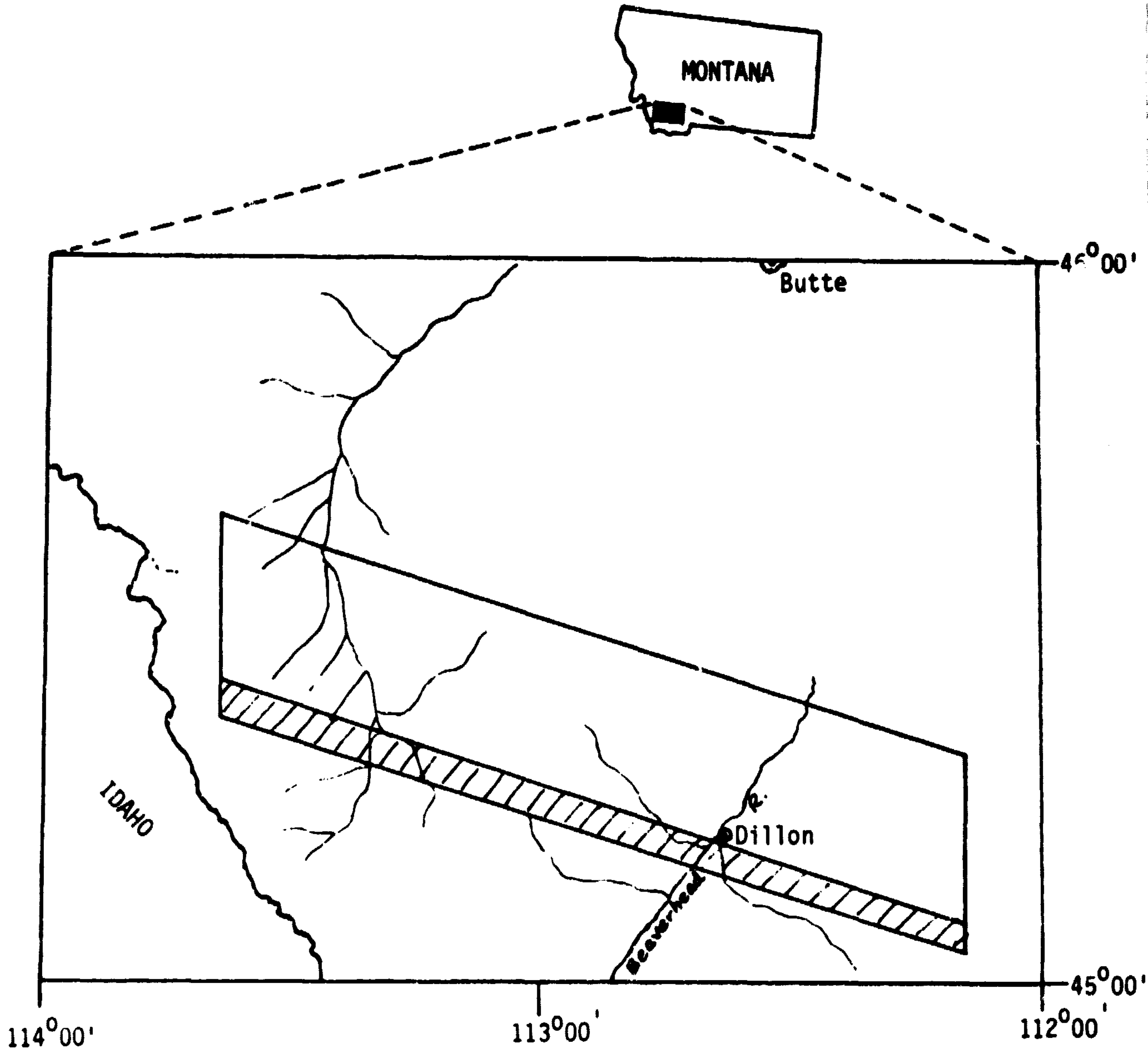

Fig. 19. Location map for USGS CUSMAP project site at Beaverhead County, Montana

2.0 Vegetated Sites

Vegetated areas require multitemporal coverage. A prioritized list of these sites follows:

2.1 Arkansas/Mississippi Wetlands Test Site

Wetland areas throughout the world often represent large areas targeted for non-renewable resource exploration. Geomorphic analysis in such terrain environments involves examination of drainage patterns and texture, and determination of plant community spatial relationships. Recent Seasat SAR investigations (MacDonald et. al., 1980; Waite et. al., 1981) have demonstrated that the presence or absence of standing water beneath a vegetation canopy may radically alter the microwave scattering characteristics in wetland areas. This improved sensitivity to changing terrain conditions appears to have considerable significance for coastal geomorphology; however, the exact mechanism operating to produce these signatures needs to be determined in order to define the range of applicability. This will require definition of the height, configuration and density of the biomass in conjunction with frequency and incidence angle of the imaging system. A study defining the parametric sensitivity of these factors offers the promise of extending this means of discriminating wetland conditions to other vegetation types as well.

The objectives of this experiment are (1) to provide definition of the parametric, microwave scattering behavior of wetland test sites, (2) to represent the observed behavior by means of heuristic and/or theoretical models, and (3) to define optimum incidence angles.

Figure 20 is a map of the Arkansas/Mississippi test sites.

2.2 Virginia Test Site

This 10,000 km^2 test site in east-central Virginia has been previously studied using Seasat L-band SAR images [Krohn, et. al., 1981] to determine the effect of forest vegetation on radar mapping. The objective of the experiment proposed here is to extend this study to include multiparameter SAR imagery of forest vegetation, and to place limits on earth backscatter models currently being devised by observing the relative grey-level relations of forest vegetation.

Figure 21 is a map of the Virginia site.

2.3 Arkansas Structural Study Site

The ability to model complex geometric and scattering phenomena which cause various geologic features (landforms) to have their characteristic expression in an image can be accomplished using

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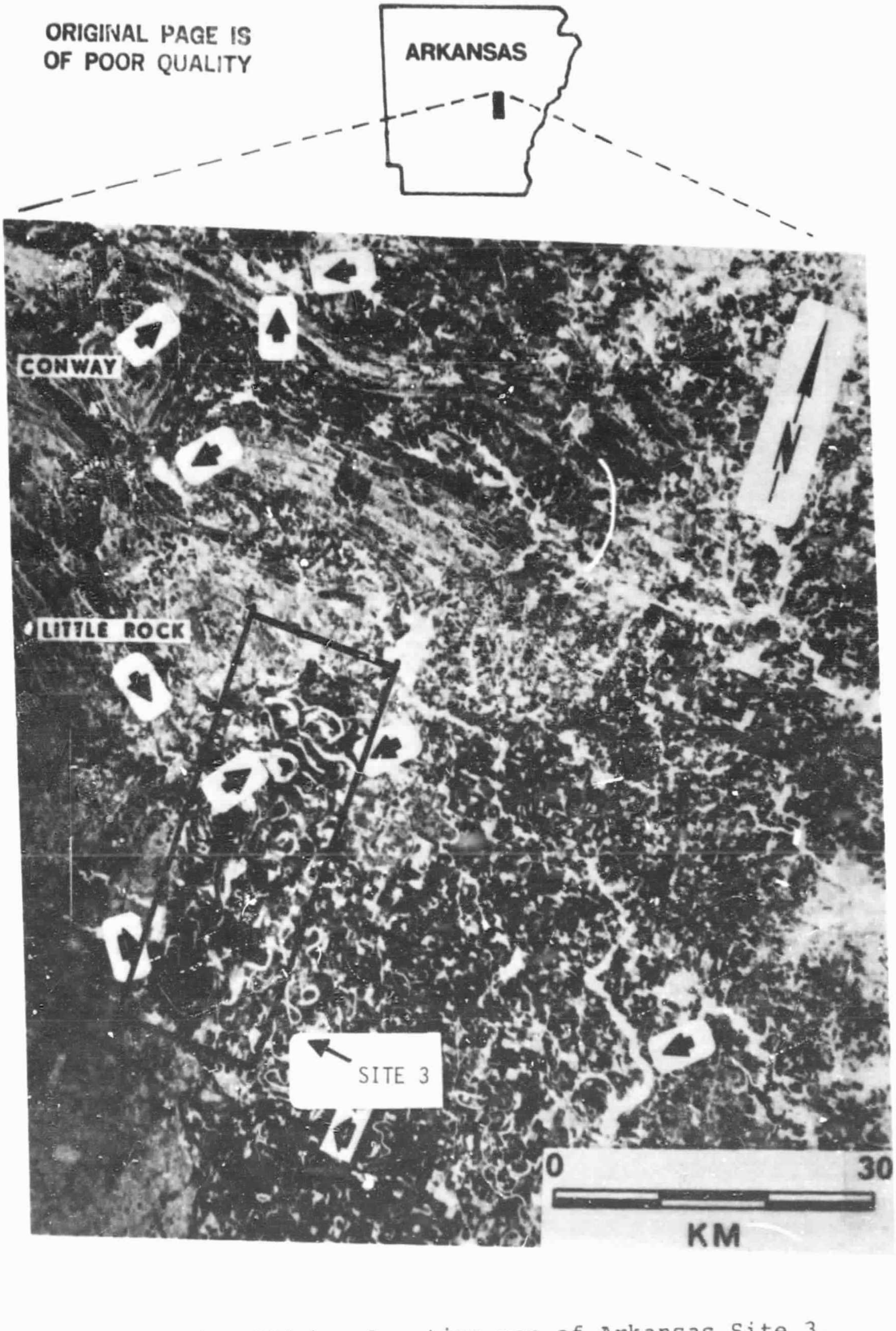

Fig. 20(a). Location map of Arkansas Site 3.

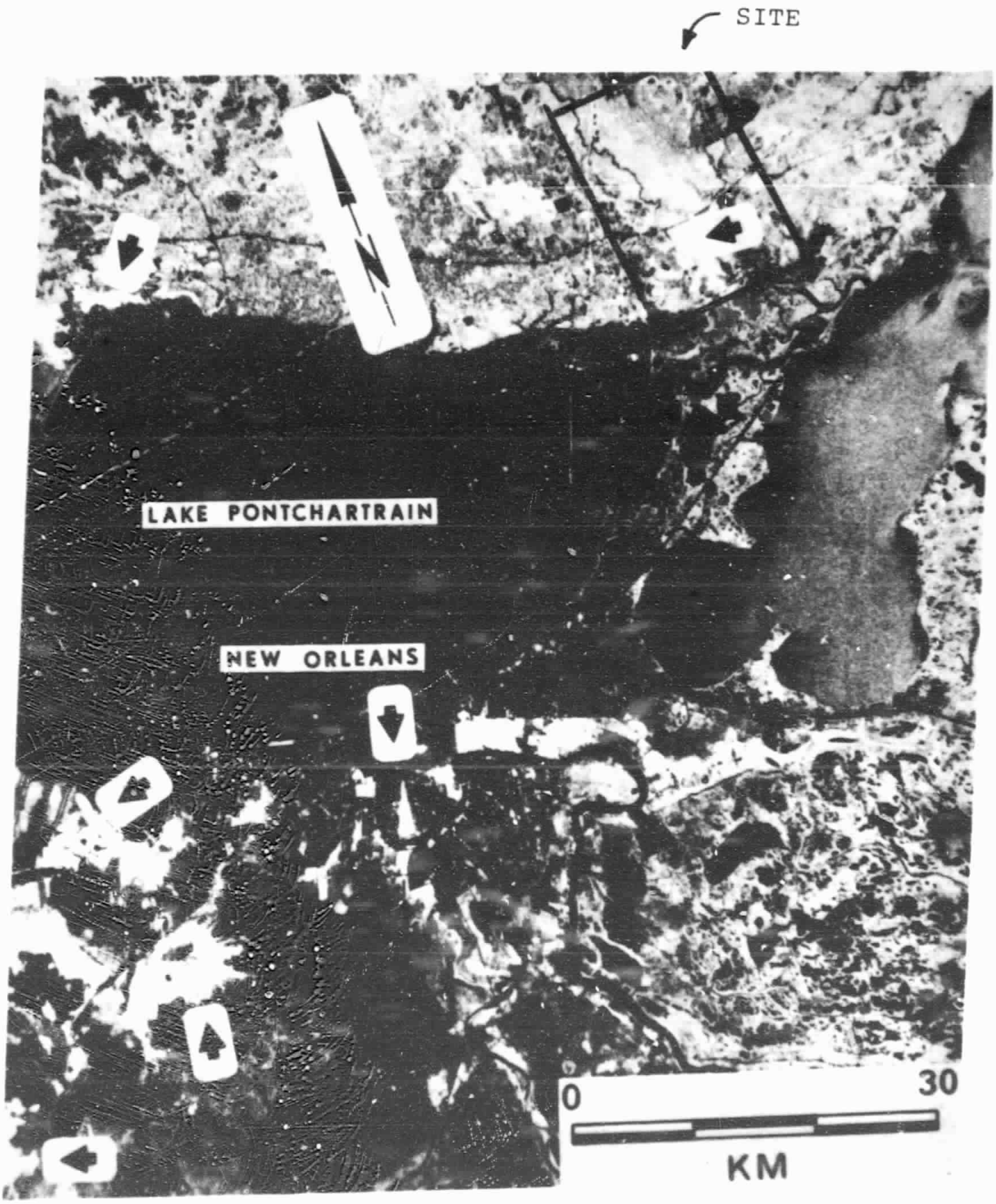

Fig. 20(b). Location map of Mississippi site.

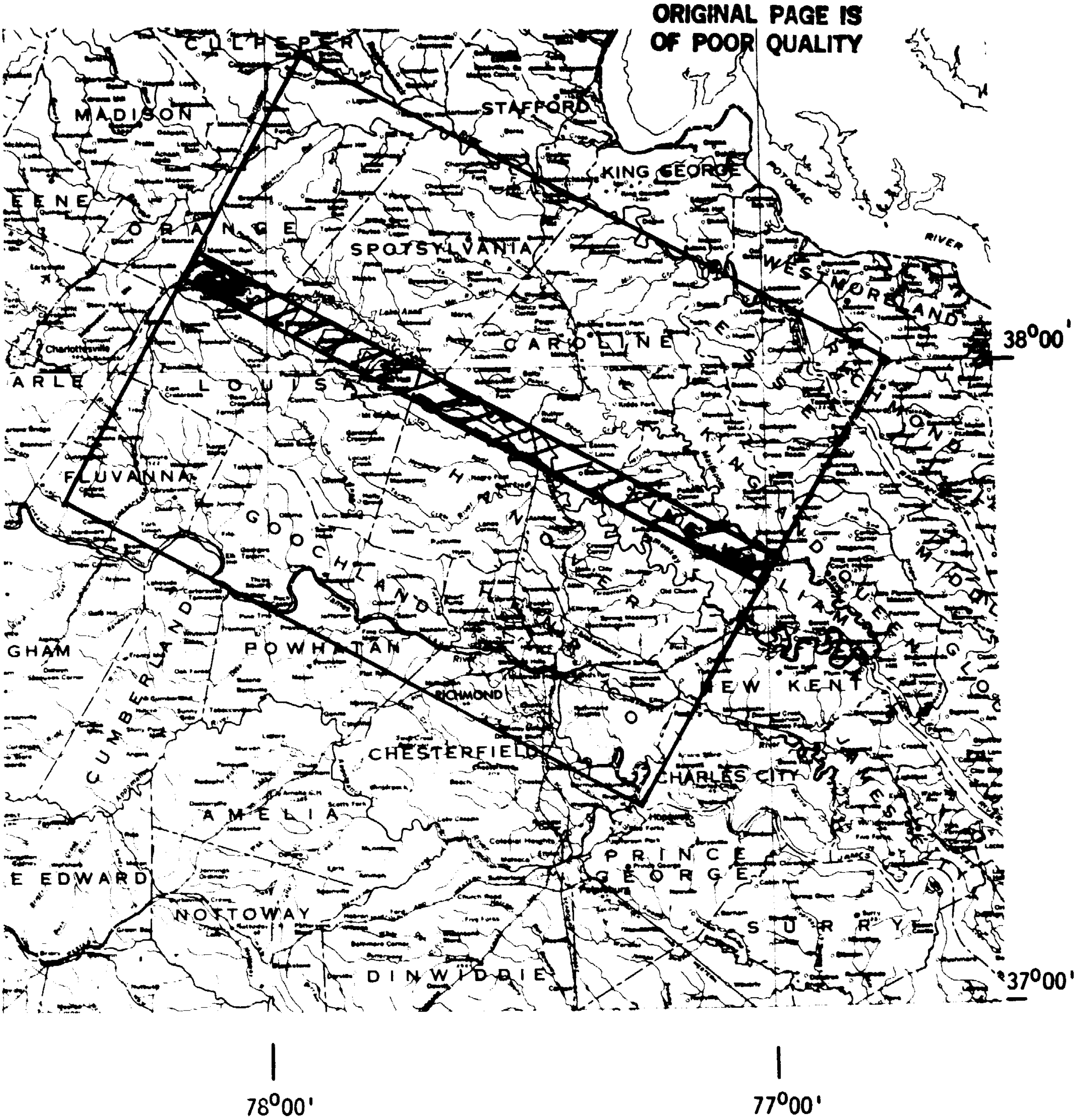

Figure 21. Location map of Virginia Test Site.

digital radar image simulation. Radar image simulation of characteristic geologic landforms can be compared with actual radar imagery of the same areas to provide a method for defining optimum sensor parameters [Kaupp et. al., 1981). The Arkansas structural test sites are characterized by contrasting rock type and structure in an area where the forest cover is mixed; deciduous and coniferous. Within the northernmost site, a positive correlation has been found between radar/Landsat - defined linear density and gas productivity (MacDonald et. al., 1981). Existing radar coverage includes Ka-, X- and L-band imagery. To the south the test site includes anticlinal and synclinal folds whose surface expression provides classic landforms. In addition to digital elevation data being available, radar coverage includes both aircraft and Seasat imagery.

The objectives of this experiment are to determine the optimum SAR sensor parameters for the definition and enhancement of geologic landforms through comparisons of radar image simulations with aircraft and satellite imagery.

Figure 22 is a map of the Arkansas structural study site.

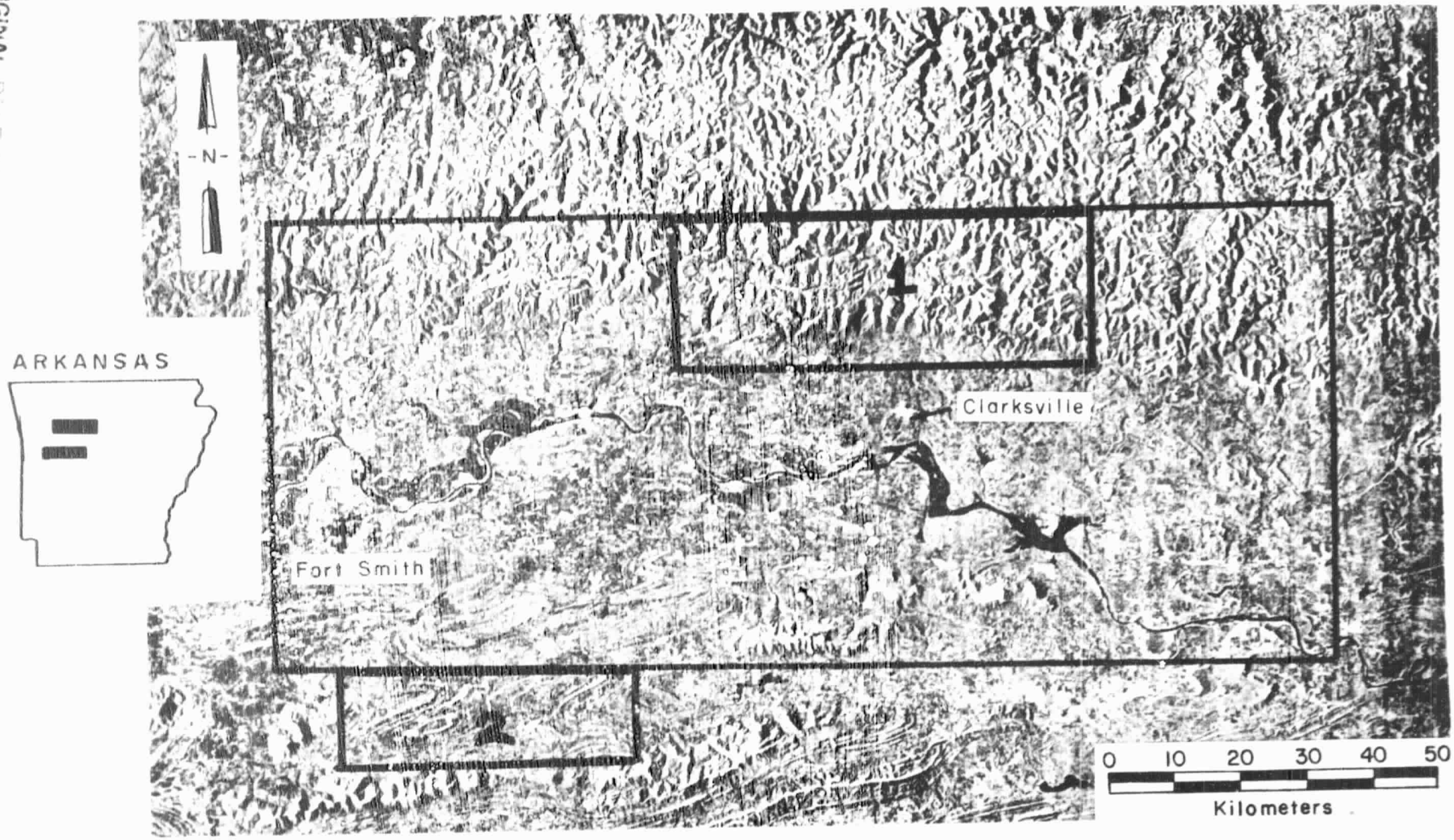

Fig. 22. Location map of Arkansas structural study site.

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APPENDIX A

AIRCRAFT TEST SITES

This Appendix furnishes the latitudes and longitudes of the previously discussed test sites and/or suggested flight lines over those sites. Where flight lines are furnished, coordinates are those of the center of the desired image swath.

C-1. Arid and Semi-Arid Sites

C-1-1. Death Valley, California

Flight Line:	Latitude	Longitude
Start	36°40' N	117°00' W
Stop	35°55' N	116°45' W

(Look direction to east)

C-1-2. Patrick Draw, Wyoming

Site Boundaries	Latitude	Longitude
	41°45' N	108°41' W
	41°25' N	108°22' W

(N-S Flight lines; 3 passes; look direction to east)

C-1-3. San Rafael Swell, Utah

Flight Line	Latitude	Longitude
Start	39°00' N	110°00' W
Stop	38°45' N	111°30' W

C-1-4. Coconino Plateau, Arizona

Site Boundaries	Latitude	Longitude
	36°00' N	110°00' W
	35°00' N	114°00' W

C-1-5. Beaverhead County, Montana

Site Boundaries	Latitude	Longitude
1.	45°7'30" N	112°07'30" W
2.	45°22'30" N	112°07'30" W
3.	45°37'30" N	113°37'30" W
4.	45°22'30" N	113°37'30" W

(No seasonal restrictions, although flight time should avoid snow in the basins.)

C-2. Vegetated Sites

C-2-1. Arkansas-Mississippi Wetlands Test Site

Site Boundaries	Latitude	Longitude
Arkansas Site	34°50' N	92°15' W
	34°50' N	92°00' W
	34°30' N	92°15' w
	34°30' N	92°00' W
Mississippi Site	30°45' N	89°55' W
	30°45' N	89°45' W
	30°35' N	89°55' W
	30°45' N	89°45' W

C-2-2. Virginia Test Site

Site Boundaries	Latitude	Longitude
	38°30' N	78°00' W
	38°00' N	76°45' W
	37°15' N	77°15' W
	37°45' N	78°30' W

(2 flights required: first in May-June, second in November - December; avoid rainy or snowy weather).

C-2-3. Arkansas Structural Study Site

Site Boundaries	Latitude	Longitude
Northernmost Site	35°50'N	94°00' W
	35°50' N	93°00' W
	35°35' N	94°00' W
	35°35' N	93°00' W
Southernmost Site	35°10' N	94°20' W
	35°10' N	94°00' W
	35°00' N	94°20' W
	35°00' N	94°00' W

APPENDIX B

RECOMMENDATIONS OF PREVIOUS STUDIES

Numerous workshop and study efforts conducted since 1974 have addressed the role of radar imagery in geological mapping and the need for improved spaceborne SARs. This appendix briefly summarizes the key points of nine of these previous studies.

1. 1974 Active Microwave Workshop, NASA/JSC (Matthews, 1974)

- Applications identified:

  Landform identification and terrain analysi

  Mineral deposits location

  Petroleum exploration

  Groundwater exploration

  Crustal motion

  Civil works

- No specific radar systems recommended

2. 1976 Space Program Imaging Radar (SPIR) Study Group, Phase 1, (Simonett, 1976)

Recommended a shuttle imaging radar with:

- o Provision for day and night observations to obtain wide array of look directions and look angles
- o Provision for two-frequency images, one of long wavelength
- o Multiple-polarization imagery for lithologic discrimination
- o R&D phase before Shuttle launch to investigate relationship between frequency, polarization and ground conditions and cover
- o Multiseason observation with controlled look angle and direction, thereby allowing season to be a pure discriminant

3. 1976 Active Microwave Users Workshop (Matthews, 1976)

- o Addressed limited understanding of geologic information from multiparameter imaging radars
- o Identified and prioritized information needs
- o Designed a detailed research program, including test sites, ground-based and aircraft sensor needs, measurements desired, schedules, and costs

4. <u>1977 NRC Committee on Remote Sensing Programs for Earth Resources Surveys</u>

- o Adequate experimental data base to support a single frequency, single polarization radar for geological exploration

- o Inadequate data base for multifrequency, multipolarization radar for soil moisture and vegetation classification

5. <u>1977 Microwave Remote Sensing Workshop (Rouse, 1977)</u>

- o Set goal of developing an adequate data base of aircraft and orbital radar imagery and technology

- o Primary applications areas identified: (1) identification and mapping of surface structural/tectonic features for energy and resources; (2) refinement of earthquake hazard maps; and (3) structural mapping for potential nuclear power plant sites and dam sites

- o Secondary applications area was identification and mapping of surface materials for improved energy and resource exploration, and for construction and engineering purposes

6. <u>1978 SPIR Study Group, Phase II Report (Simonett, 1978)</u>

- o Refined earlier 1976 report

- o Further emphasized need for active microwave image measurements from orbital altitude

7. <u>1978 Shuttle Active Microwave Facility Review (Rouse, 1978)</u>

Recommended:

- o Active microwave imagery be obtained of economically significant areas of globe
- o Second generation SIR include an X-band imager with incident angle capability of at least 70°, spatial resolution of 30m, five-look spatial averaging, swath of 50km
- o Research programs be initiated using ground-based and aircraft sensors to improve understanding and utility of multiparameter active microwave imaging data in geologic applications
- o Initiation of geology experiments program using Seasat-A and SIR-A

8. <u>1979 Snowmass Radar Geology Workshop (Harrison, 1980)</u>

Recommended:

- o Investigation of frequency, polarization effects in target/energy interaction
- o Study of effects of look direction and depression angle on image interpretability over various terrain types
- o Determine necessary dynamic range
- o Determine necessary calibration
- o Improve digital data processing (to preserve dynamic range and system calibration, permit image signature quantification and analysis, facilitate comparison with other types of data, etc.)
- o Place an X-band, 45^{o} incidence angle, like-polarized SAR into orbit as soon as possible

9. <u>1980 ERSAR Report (Rouse, 1980)</u>

Recommendations:

- o Provide extensive land SAR data base with large incidence angle spaceborne SAR
- o Determine quantitative relationship between geologic surface variables and radar system parameters
- o Use L-, C-, and X-band dual-polarized aircraft SAR imagery
- o Determine utility of radar images for relation to surface and lithologic units, drainage pattern mapping, lineament mapping - using Seasat-A and SIR-A imagery

APPENDIX C

FIREX NON-RENEWABLE RESOURCES STUDY TEAM

Dr. Keith R. Carver, Chairman
Code EL-4
NASA Headquarters
Washington, D.C. 20546
(202)755-6038

Dr. Anthony W. England, Co-chairman
Code CB
Lyndon B. Johnson Space Center
National Aeronautics and Space Administration
Houston, TX 77058
(717)483-2411

Dr. Harold C. MacDonald
Department of Geology
University of Arkansas
Fayetteville, AR 72702
(501)575-4748

Dr. Charles Elachi
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91102
(213)354-5673

Dr. Aderbal Correa
Conoco, Inc.
13949 W. Colfax Ave., Suite 100
P.O. Box 821
Golden, CO 80401
(303)232-0727, ext. 32

Dr. Dennis Krohn
Mail Stop 927
Geological Survey
Department of the Interior
Reston, VA 22092
(703)860-6994

Dr. Andrew Blanchard
Remote Sensing Center
Texas A&M University
College Station, TX 77843
(712)845-5422

Dr. James V. Taranik
Code EL-4
NASA Headquarters
Wasnington, D.C. 20546
(202)755-3752

The Study Team was greatly assisted by, and is indebted to, Professor V. H. Kaupp of the University of Arkansas, who provided the radar simulations shown in this report.