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A GEOLOGIC ANALYSIS OF THE SIDE-LOOKING AIRBORNE RADAR IMAGERY

OF SOUTHERN NEW ENGLAND

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CONTENTS

CONTENTS (cont.)

ILLUSTRATIONS

ILLUSTRATIONS (cont.)

ABSTRACT

Analysis of the side looking airborn radar imagery of Massachusetts, Connecticut and Rhode Island indicates that radar shows the topography in great detail. Since bedrock geologic features are frequently expressed in the topography the radar lends itself to geologic interpretation.

The radar was studied by comparisons with field mapped geologic data first at a scale of approximately 1:125,000 and then at a scale of 1:500,000. The larger scale comparison revealed that faults, minor faults,joint sets, bedding and foliation attitudes, lithology and lithologic contacts all have a topographic expression interpretable on the imagery. Surficial geologic features were far less visible on the imagery over most of the area studied. The smaller scale comparisons revealed a pervasive, near orthogonal fracture set cutting all types and ages of rock and trending roughly N40°E and N30°W. In certain places the strike of bedding and foliation attitudes and some lithologic contacts were visible in addition to the fractures.

Fracturing in southern New England is apparently far more important than has been previously recognized. This new information, together with the visibility of many bedding and foliation attitudes and lithologic contacts, indicates the importance of radar imagery in improving the geologic interpretation of an area.

INTRODUCTION

Side Looking Airborn Radar (SLAR), a remote sensing device, was used to make imagery of Massachusetts in 1968 and Connecticut and Rhode Island in 1970. The imagery was made by the Grumman Aircraft Engineering Corporation with the cooperation of the U.S. Army for the U.S. Geological Survey as a project under the NASA program. The area imaged is referred to as southern New England and covers approximately 37,503sqkm. In all, four mosaics were made; an east and a west looking mosaic for Massachusetts and a north and a south looking mosaic for Connecticut and Rhode Island.

Geologic Setting

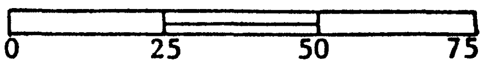
Southern New England lies completely within the crystalline portion of the Appalachian mountain system. The bedrock consists of tightly folded and faulted, low to high grade, metasedimentary and metavolcanic rocks intruded by igneous rocks of various ages. The pattern of metamorphic and plutonic rocks is broken by unmetamorphosed Triassic rocks in the Connecticut Valley and by relatively low grade Carboniferous rocks (except in the western part of the Naragansett basin in Rhode Island where the rocks are in the sillimanite zone of metamorphism) in fault basins in eastern Massachusetts and Rhode Island.

Resistant Precambrian gneisses are exposed in western Massachusetts and western Connecticut in a series of roughly north-south trending massifs (Figure 1). West of these Precambrian rocks a lower Paleozoic miogeosynclinal sequence of slightly metamorphosed limestones and sandstones is found along with the more resistant phyllites and schists of the Taconic sequence.

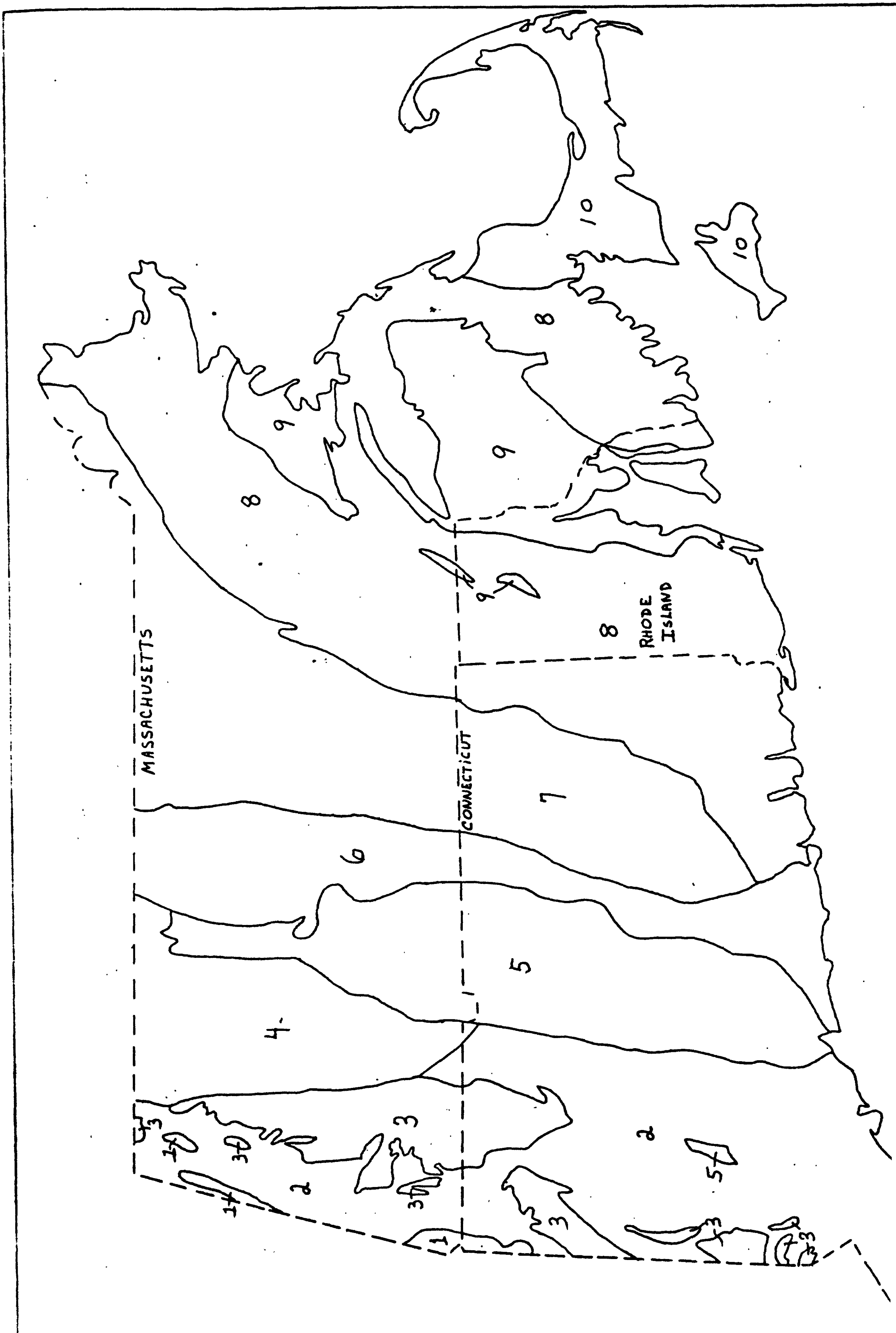
Figure 1 - Location Map Of The Major Geologic Areas In Southern New England.

1. Taconic sequence, lower Paleozoic phyllites and schists.
2. Lower Paleozoic metasedimentary and metavolcanic rocks with plutonic rocks.
3. Precambrian anticlinorial massifs.
4. Connecticut Valley Synclinorium.
5. Triassic basins.
6. Bronson Hill Anticlinorium.
7. Merrimack Synclinorium.
8. Precambrian and Paleozoic metasedimentary, metavolcanic and plutonic rocks.
9. Late Paleozoic sedimentary basins.
10. Area underlain by Atlantic Coastal Plain deposits and Quaternary drift.

Scale



Kilometers


MASSACHUSETTS
CONNECTICUT
RHODE ISLAND
1
1+
2
3
3+
4
5
5+
6
7
8
9
10

The Taconic rocks are eugeosynclinal sediments thrust from the east to the west during Ordovician time and which now unconformably overlie the miogeosynclinal rocks.

East of the Precambrian rocks is a eugeosynclinal sequence of Paleozoic rocks in the Connecticut Valley Synclinorium. The metamorphic terrain is here broken in central Massachusetts and central Connecticut by the unmetamorphosed sedimentary and volcanic rocks of the Triassic basin. East of the Triassic rocks two roughly north-south trending structural blocks, the Bronson Hill Anticlinorium and the Merrimack Synclinorium, cover Massachusetts and Connecticut with Paleozoic metasedimentary and metavolcanic rocks. Separated from the Merrimack Synclinorium by a series of northeast trending faults are the Precambrian and Paleozoic igneous and metamorphic rocks of eastern Massachusetts and Rhode Island. Superimposed on these are the fault bounded Carboniferous sedimentary basins.

The area underwent orogenic activity at least six different times; twice in the Precambrian, in the middle Ordovician (the Taconic orogeny), in the middle Devonian (the Acadian orogeny), in the Permian (the Allegheny orogeny), and finally in the Triassic (the Palisades orogeny). After the Palisades orogeny erosion took place until the present. During the Pleistocene epoch at least four different periods of glacial advance and retreat occured.

Purpose of Study

The purpose of this study is to determine (1) the geologic usefulness of radar imagery in this glaciated, metamorphosed and structurally complex terrain, and (2) to see if the geology of the region can be better understood and more accurately mapped using SLAR imagery.

Method of Study

The method used to analyze the geologic usefulness of radar imagery was to compare field mapped geology to the imagery at the same scale. This was done first with three small areas at a scale of approximately 1:125,000 and then with the entire three state region at a scale of approximately 1:500,000. The small areas were studied to determine in detail what kinds of geologic features can be interpreted from radar imagery. The information obtained from these detailed studies was used to make a radar-geologic map of Massachusetts, Connecticut and Rhode Island at a scale of approximately 1:500,000. This geologic map was constructed on an overlay of the Massachusetts west looking imagery and the Connecticut and Rhode Island south looking imagery.

Acknowledgements

The author wishes to express his gratitude to Dr. J.C. Hepburn of Boston College, to M.H. Pease Jr. and D.W. O'Leary of the U.S. Geological Survey, for reading and reviewing the report, and to Henrietta Gatto for her untiring assistance and encouragement. The work was financially supported by the U.S. Geological Survey, and the report was submitted in partial fullfillment of the requirements for a Master of Science degree from Boston College.

SIDE-LOOKING AIRBORN RADAR (SLAR)

Basic Operation of SLAR Systems

Radar (RAdio Detection And Ranging) uses energy in the radio wave portion of the electromagnetic spectrum. It has wavelengths longer than visible light but shorter than AM type radio waves. These wavelengths provide radar with some of the sensing capabilities of visible light and some of the penetrating capabilities of radio waves. Radar can penetrate clouds, dust, haze and almost all forms of atmospheric interference. SLAR systems have wavelengths ranging from more than 1 meter to less than 1 centimeter and frequencies ranging from 220 megaherz to 40,000 megaherz. The radar used in this study has wavelengths from 3.75cm to 2.40cm and frequencies from 8000MHz to 12,500MHz and it is assigned the letter code X (X-band).

An aircraft equipped with a SLAR system flies in a straight line, at a constant altitude and speed and along a determined path (called the flight path or ground track). As it moves an onboard transmitter generates short pulses of radio frequency (radar) energy. These pulses are propagated towards the earth not directly beneath the aircraft but off to one side or the other (hence "side looking"). This allows the aircraft to image two strips of terrain simultaneously and creates the shadow affect which greatly aides in topographic interpretation. The energy travels at the speed of light through the atmosphere until it intercepts the surface of the earth. At this interface some of the energy is reflected back to the aircraft, some is absorbed into the earth and some is scattered into the atmosphere away from the aircraft. That portion of the energy returned to the aircraft is received by the antenna and converted to a video signal by the receiver. The video signal is displayed on a cathode-ray tube. Return signals from subsequently transmitted pulses are displayed on the cathode-ray tube in the same position as the previous ones. However, by moving photographic film past the cathode-ray tube display line at the same velocity as the aircraft an image of the terrain can be recorded as a continuous strip map.

Terrain-Energy Interaction

The amount of radar energy received back at the aircraft determines the brightness of the final image (high energy return = bright image, low energy return = dark image). In turn, the amount of radar energy detected depends on the reflecting properties of the terrain surface. Radar waves are reflected either specularly (i.e. mirror-like) or diffusely (i.e. in all directions). Smooth surfaces reflect specularly. Rough surfaces reflect diffusely. Surface roughness is defined relative to the wavelength of the impinging radar waves. If the surface has a roughness of approximately 1/2 the wavelength or less it will reflect specularly and appear smooth on the imagery. Surfaces with a roughness greater than 1/2 the wavelength reflect diffusely and appear rough on the imagery. Short wavelengths (e.g. less than 1cm) lose atmospheric penetration capabilities and long wavelengths (e.g. greater than 5cm) can make rough terrain appear smooth.

Angle of Incidence

The angle of incidence of the radar energy is a very important factor in the amount of that energy returned to the aircraft. It is defined as the angle between the impinging radar beam and a perpendicular to the incident surface at the point of incidence. Small incidence angles provide high energy returns. Large incidence angles provide low energy returns. On a flat terrain the incidence angle changes continuously from about 10° in the near range of the image strip (close to the aircraft) to about 70° in the far range of the image strip (away from the aircraft). If two or more terrain surfaces are planar and perpendicular to each other (e.g. buildings and streets) a high energy return is experienced no matter what the incidence angle.

Surface Configuration and Look Direction

Because illumination by radar is unidirectional (perpendicular to the flight path and/or parallel to the look direction) the amount of energy returned is controlled to some extent by the configuration of the terrain and the look direction that images it. Large terrain features such as hills and valleys are important factors in the control of energy return. The shape and size of terrain features is important when look direction is considered especially where elongate shapes are involved. Imaging an elongate ridge from a direction perpendicular to the trend of the ridge will return more energy than imaging it from a direction parallel to the trend of the ridge.

All of the above parameters join together to provide an image of the terrain. Using black and white and all shades of gray a strip map similar to a shaded relief map is produced. This map shows the topography in an enhanced format. However, because of terrain factors and sensor limitations, many distortions in the final image exist.

Distortions

Shadow

Black shadows are an obvious distortion in a radar image. Unidirectional illumination, such as that afforded by SLAR systems, will illuminate only those objects directly in the line of illumination. Other areas will be shadowed. Also, since the angle of incidence increases in the far range of an image strip, more extensive shadowing will occur there than in the near range. This is very similar to solar shadowing in the late afternoon. Radar shadows may inhibit geologic interpretation.

Slant Range and Ground Range Formats

SLAR systems use either a slant range or a ground range format. In a ground range format the distance between two features on the image is directly proportional to their actual spacing on the ground. In a slant range format the spacing between two features on the image is directly proportional to the time interval between the radar energy interception of the features and not to the distance between them. Slant range formats (like the one used in this study) do not present a scale accurate picture.

In a slant range format the range scale (the range direction is perpendicular to the flight path or parallel to the look direction) will vary with any variation in aircraft altitude. The azimuth scale (azimuth direction is parallel to the flight path) will vary if the synchronization between aircraft speed and film speed is varied.

Near Range Compression

More important than these aircraft problems is the continuous scale change in the range direction. In the far range the scale distortion is slight. In the near range, however, considerable compression of the imagery occurs. Thus scale distortions as well as distortions in geometric shape may occur in the near range. Linear features, such as ridges and valleys, which are parallel or perpendicular to the look direction show little distortion in orientation in a slant range format. Linear features oriented obliquely to the look direction do experience orientation distortions in the near range (e.g. small scale features may be elongated parallel to the flight path).

<u>Mosaic Distortions</u>

When the individual image strips are layed side by side to produce a radar mosaic, some distortions result. The strip to strip contacts are not exact and may cover certain features. Many thin parallel lines, called scan lines, are visible. These are caused by antenna instabilities. The mosaics used in this study are uncontrolled. The strips are matched to each other and not to a base map. For this reason a scale difference exists between mosaics of the same area made from two opposing look directions.

More refined radar systems have most of the above mentioned distortions rectified by computer both during and after the flight. Computer-adjusted radar mosaics, not available for this study, offer a very close approximation to a planimetric map from which accurate topographic and geologic maps can be made.

Radar Imagery Used in This Study

The radar images used in this study were made by X-band, slant range, side looking airborn radar. Eight separate mosaics were studied at a scale of approximately 1:500,000. These include an east looking and a west looking mosaic for Massachusetts and a north looking and a south looking mosaic for Connecticut and Rhode Island. Both enhanced and unenhanced mosaics were made for each look direction in each state, thus making a total of eight mosaics. An enhanced mosaic is one which has been modified to reduce tonal contrast between strips. However by reducing the contrast some resolution is lost.

The aircraft flew at an altitude of 2440m and at a speed of 180 knots. Imaging was done in both directions simultaneously and covered a swath approximately 25km wide on either side of the aircraft. In Massachusetts the flight direction was parallel to the western border of the state (N15°E) and in Connecticut and Rhode Island the flight direction was east-west.

The imagery was made with a Motorola AN/APS - 94 system in Massachusetts and was flown in a Grumman-built OV-IB Mohawk aircraft. The film was laboratory printed. The Connecticut imagery was made with the slightly different APS-94D system and the film was processed on board.

Westinghouse, using their AN/APQ - 97 system, made on imaging pass over a part of southern New England prior to the Motorola imagery making. The quality of this imagery is good but because of space and time considerations it will not be discussed in this report (this Westinghouse imagery is not available to the public).

Previous Work in SLAR Imagery Interpretation

The first and most familiar use of reflected radio waves (radar) was for military targeting purposes. The targeting is done either by air to air or ground to air transmission of the radar energy. And if the surface of the earth should happen to intercept some of this energy it was considered clutter and undesirable. Dr. E.P. Smith (1948) first reported on some non-military applications of radar in the field of terrain analysis. Since then work on this type of radar imagery has progressed. Geology is a more recent benefactor of the discovery. In the early days of the study of SLAR imagery volcanic terrains were studied in particular because of a probable similarity with the lunar landscape.

Much work has been done to determine the usefulness of radar imagery in the study of the terrain. Some suggested uses are the study of geologic structure, geomorphic features, cultural patterns of land use (Simons, 1965), regional scale physiographic features (Dellwig and others, 1968), surface drainage and surface configuration, and vegetation (Viksne and others, 1969).

Ferrante (1967) listed those factors which he believes control the intensity of the returned radar signal; (1) direction from which the terrain is imaged, (2) the roughness of the surface imaged, and (3) the geometry of the surface imaged. Hackman (1967), in a study of flat lying sedimentary rocks in southern Utah, found that changes in returned signal intensity did not always reflect lithologic changes.

A study of the radar imagery of the Darien Province of Panama by H.C. Mac Donald (1969) provided some basic guidelines for the geologic interpretation of radar. He found that geologic structure often has an excellent correspondence with the topography. Folded or faulted rocks weather and erode differentially and they reveal their presence at the surface of the earth. Wing and others (1970) found exactly the same thing to be true in their study of the radar imagery of the Burning Springs area in West Virginia.

MacDonald and others (1969) also found that faults are expressed on radar as long, strong lineaments which are persistent and may cut across regional structural trends. In a study of the St. Francis Mountains in southeast Missouri, Gillerman (1970) noted that a certain lineament was defined by alignment of drainage and by abrupt changes in the course of streams which intersect the lineament. He interpreted this lineament as a fault because it is long, straight and altered the drainage.

Joints are expressed on radar as shorter, criss-cross lineaments and joint systems, rather than individual joints are shown on radar imagery (MacDonald, 1969). MacDonald (1969) also notes that the distinction between faults and joints on radar imagery is difficult.

Radar is also suited for the sequential imaging of coastlines to monitor changes in mud flats, beach ridges, natural levees, zones of breaking surf and offshore sediment transport (MacDonald and others, 1971).

Previous workers in radar geology have pointed out some advantages and disadvantages. Airborn radar systems are all weather, round-the-clock systems (Simons, 1965, Hackman, 1967, and Dellwig and others, 1968). Radar can image large areas with few imaging passes and therefore is important in regional scale studies. Also, the shadow enhancement of the topography greatly aids in the observation and interpretaion of geologic features (Reeves, 1969 and Hackman, 1967).

Some disadvantages of radar imagery found by previous workers are the lack of both stereoscopic coverage and very fine resolution (Simons, 1965). MacDonald and others (1969) found that near range portions of the imagery are of poor quality because of the absence of good shadowing. Look direction is also an important disadvantage if the terrain is imaged from a direction parallel to the main structural trend of the region (Wing and others, 1970, MacDonald and others, 1969 and Dellwig and others, 1968). The differentiation of lithology is generally more difficult on radar imagery than on conventional aerial photography (Hackman, 1967).

Fundamentals of Radar Imagery Interpretation

The terms tone, texture and lineament need to be defined before a discussion of radar imagery interpretation can be pursued. Tone is the intensity of white or the intensity of black on the image. Texture is the frequency of tone changes over a given area. Tone is a fundamental element of texture and one does not exist without the other. The shape, size and patterns of the topography give the image its texture. A radar lineament is a linear or curvilinear change in tone. Lineaments can appear on the imagery as either linear or curvilinear boundaries between adjacent regions of different signal return or as sharp, linear or curvilinear tone changes within a larger area of uniform signal return.

To demonstrate the basics of radar imagery interpretation I have used three sample areas which will be discussed in detail. Before the samples are given, however, four questions should be introduced into the readers mind;

1. Does radar imagery accurately "see" the topography?
2. Are bedrock geologic features reflected in the topography?
3. Do glacial features affect the way bedrock geologic features are reflected in the topography?
4. If radar accurately "sees" the topography, and if bedrock geologic features are reflected in the topography, what geologic interpretations can be made from radar imagery?

INTERPRETING GEOLOGY FROM RADAR IMAGERY

Three examples will be used to discuss in detail how radar imagery is interpreted. The first two examples are used to demonstrate how bedrock and surficial geology can be studied using radar. The third example shows only the bedrock geology but will be used to evaluate the importance of orthogonal look direction coverage to geologic interpretation.

Example # 1

The area of example # 1 is located on figure 2. It covers four 7-1/2 minute quadrangles in west-central Massachusetts and equals approximately 563sqkm. Figures 3a and 4 are photographs of area # 1 taken from the unenhanced east looking and west looking mosaics of Massachusetts and enlarged approximately four times. They represent the same area as the four quadrangles shown on figure 2. Because they are photographs of a mosaic the quality is not as good as it could be if the original strips were studied separately (as was actually done). Figure 3a will be used for the following discussion and figure 4 was included for a comparison of two opposing look directions.

There are three major radar distortions present on figure 3a; they are (1) scale distortion, partly caused by the slant range presentation of this imagery and partly caused by the inexact positioning of each mosaic strip. The scale error could be as high as 4% (Kover, 1974, oral communication), (2) scan lines, these are the fine lines that can be seen perpendicular to the flight lines (flight line here is N15°E), and (3) radar shadow, radar shadow is present almost everywhere; it is always on the opposite

Figure 2 - Location map of the Shelburn Falls, Greenfield, Williamsburg and Mount Toby Quadrangles in west-central Massachusetts.

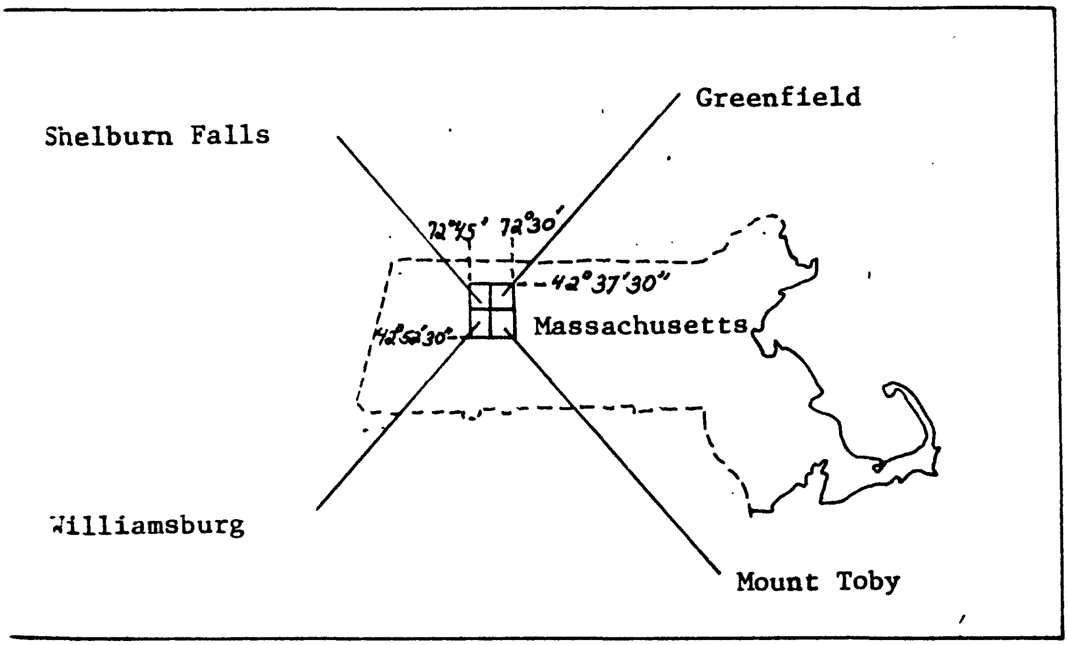

Shelburn Falls
Greenfield
72°45' 72°30'
42°37'30"
42°52'30"
Massachusetts
Williamsburg
Mount Toby

Figure 2

Figure 3a - Enlarged radar imagery of the Shelburn Falls, Greenfield, Williamsburg and Mount Toby Quadrangles, east looking, scale approximately 1:114,048 enlarged from a scale of approximately 1:500,000. + indicates quadrangle corner.

Figure 3b - Interpretive radar-geologic map of the Shelburn Falls, Greenfield, Williamsburg and Mount Toby Quadrangles made to overlay the enlarged east looking imagery (fig. 3a), scale approximately 1:114,048.

———— contact clearly interpretable on radar imagery and also appears on the mapped geology.

- - - - - contact difficult or impossible to interpret on radar imagery but appears on mapped geology.

———— fault clearly interpretable on radar imagery and also appears on mapped geology.

- - - - fault difficult or impossible to interpret on radar imagery but appears on mapped geology.

-··-·-·· fracture interpreted on radar imagery that does not appear on mapped geology.

—Δ— strike and dip of bedding and/or foliation
strike interpreted from radar imagery
dip obtained from mapped geology
length of line approximates length of lineament.

+ indicates corner of quadrangle.

↑ north

0 1 2 3 4

approximate scale in kilometers

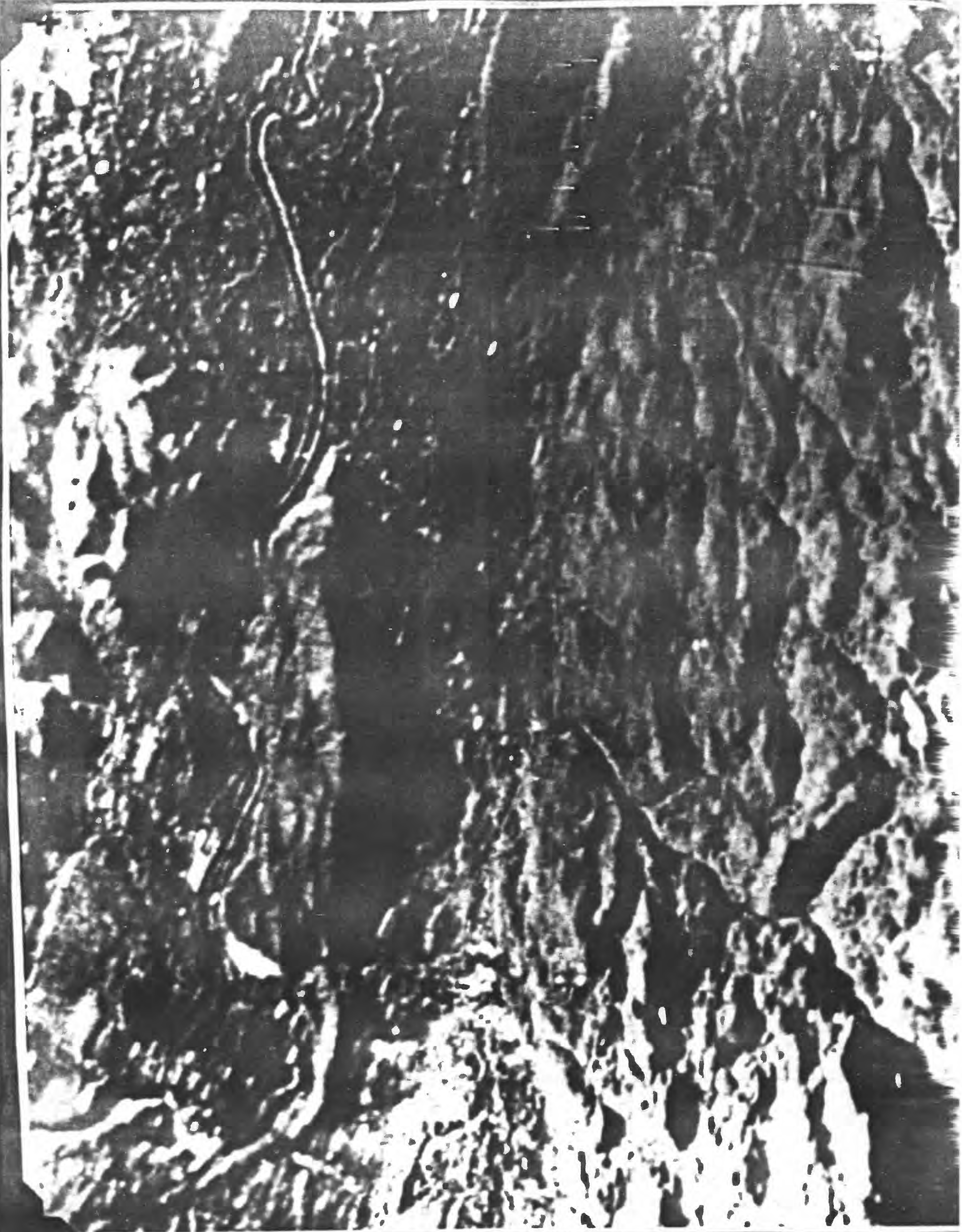
no page 21

Figure 4 - **Enlarged radar imagery of the Shelburn Falls, Greenfield, Williamsburg and Mount Toby Quadrangles, west looking, scale approximately 1:114,048 enlarged from a scale of approximately 1:500,000. + indicates quadrangle corner.**

north

0 1 2 3 4

approximate scale in kilometers



side of a topographic high from the aircraft and although it can black out certain parts of the image the shadowing is what enhances the topography.

Does Radar Accurately "See" the Topography?

Figure 5a is a topographic map of the area at approximately the same scale as the radar imagery with the generalized geology drafted onto it (the geology will be discussed in a later section). The radar imagery, using black and white and shades of gray, presents an enhanced picture of the terrain similar to that of a shaded relief map. The major aspects of the topography are clearly visible and certain aspects of it are greatly enhanced. Topographic lineaments (i.e. valleys and ridges) are much more prominent on the radar imagery (due to the shadowing affect) than on the topographic map, as can be seen by comparing the topography of the western half of figure 5a with the topography of the same area as seen on the western half of either figure 3a or 4.

Are Bedrock Geologic Features Reflected in the Topography?

The generalized bedrock geology of the Shelburn Falls (Segerstrom, 1956), Greenfield (Willard, 1952), Williamsburg (Willard, 1956) and Mount Toby (Willard, 1951) quadrangles is shown on figure 5b. Figure 6 shows the geologic structure of the same area. A comparison of the lithology and structure of the area with the radar imagery (fig. 3a) reveals the following facts;

Figure 5b shows a large area of Triassic sedimentary rocks with a north-south trending ridge of Triassic basalt lying within it. The radar imagery of this area (fig. 3a) clearly

Figure 5a - Topographic map of the area of example # 1.

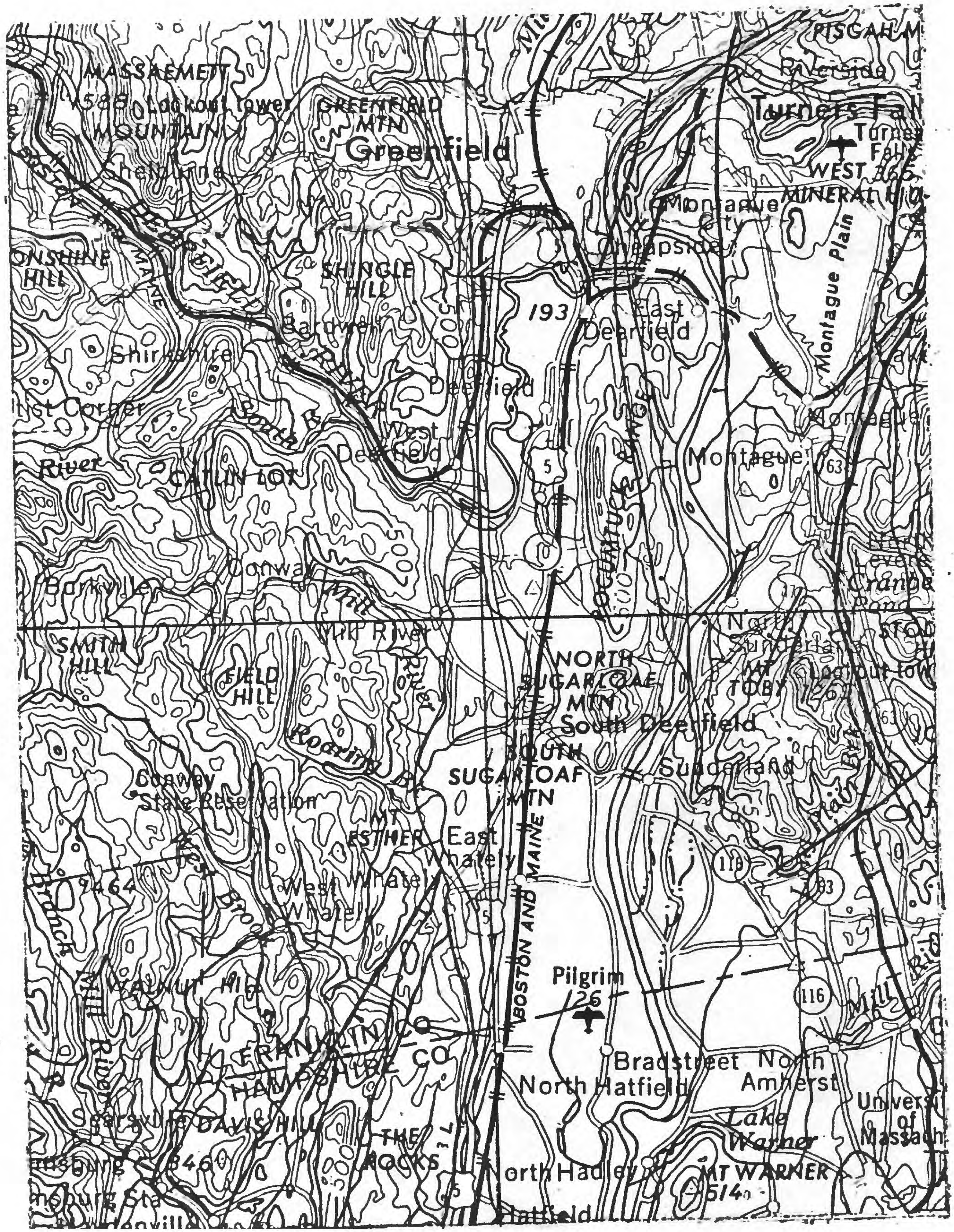

MASSAEMETT
MOUNTAIN
Lookout tower
GREENFIELD
MTN
Greenfield
Shelburne
SHINGLE
HILL
Bardwell
Shirkshire
Deerfield
West
Deerfield
River
CATLIN LOT
Conway
Barkville
Mill
Mill River
SMITH
HILL
FIELD
HILL
Roaring
Conway
State Reservation
MT
ESTHER
East
Whately
West Whately
Whately
WALNUT HILL
FRANKLIN CO
HAMPSHIRE CO
DAVIS HILL
THE
ROCKS
North Hadley
Hatfield
North Hatfield
Bradstreet
North
Amherst
Lake
Warner
MT WARNER
514
Pilgrim
126
BOSTON AND MAINE
NORTH
SUGARLOAF
MTN
South Deerfield
SOUTH
SUGARLOAF
MTN
Sunderland
MT
TOBY
North
Sunderland
East
Deerfield
193
Cheapside
Montague
Montague Plain
Turners Falls
Riverside
WEST
MINERAL HILLS
PISGAH

Figure 5a

Figure 5b - "Geologic" map of the Shelburn Falls, Greenfield, Williamsburg and Mount Toby Quadrangles showing lithologic contacts and faults on a topographic base at a scale of 1:125,000 and a contour interval of 100ft.

TRIASSIC

1 -sedimentary rocks, including coarse conglomerate, thin bedded shaley sandstone, and micaceous and calcareous arkosic sandstone and conglomerate.

2 -unmetamorphosed basalt flow.

CARBONIFEROUS ?

3 -medium grained, biotite, muscovite granodiorite with pegmatite.

4 -medium to coarse grained, foliated quartz diorite.

SILURO-ORDOVICIAN

5 -carbonaceous phyllite with thin beds of quartzite.

6 thin bedded phyllite and feldspathic quartzite with beds of arenaceous limestone, fine grained, schistose amphibolite, garnetiferous quartz, mica schist with quartzite beds, schistose marble and schistose quartzite.

PRE-MIDDLE ORDOVICIAN

7 -siliceous gneiss with beds of amphibolite.

PRE-TRIASSIC

8 -gneissic granite

9 -coarse grained, quartz, muscovite schist with biotite and garnet.

10 -fine grained, hornblende schist with beds of feldspathic quartzite.

11 -quartz, muscovite, biotite schist.

12 -quartz, hornblende, biotite gneiss.

———contact

——fault with bar and bell on downthrown side

north

0 1 2 3 4

approximate scale in kilometers

Map and explanation compiled from sources mentioned in text.

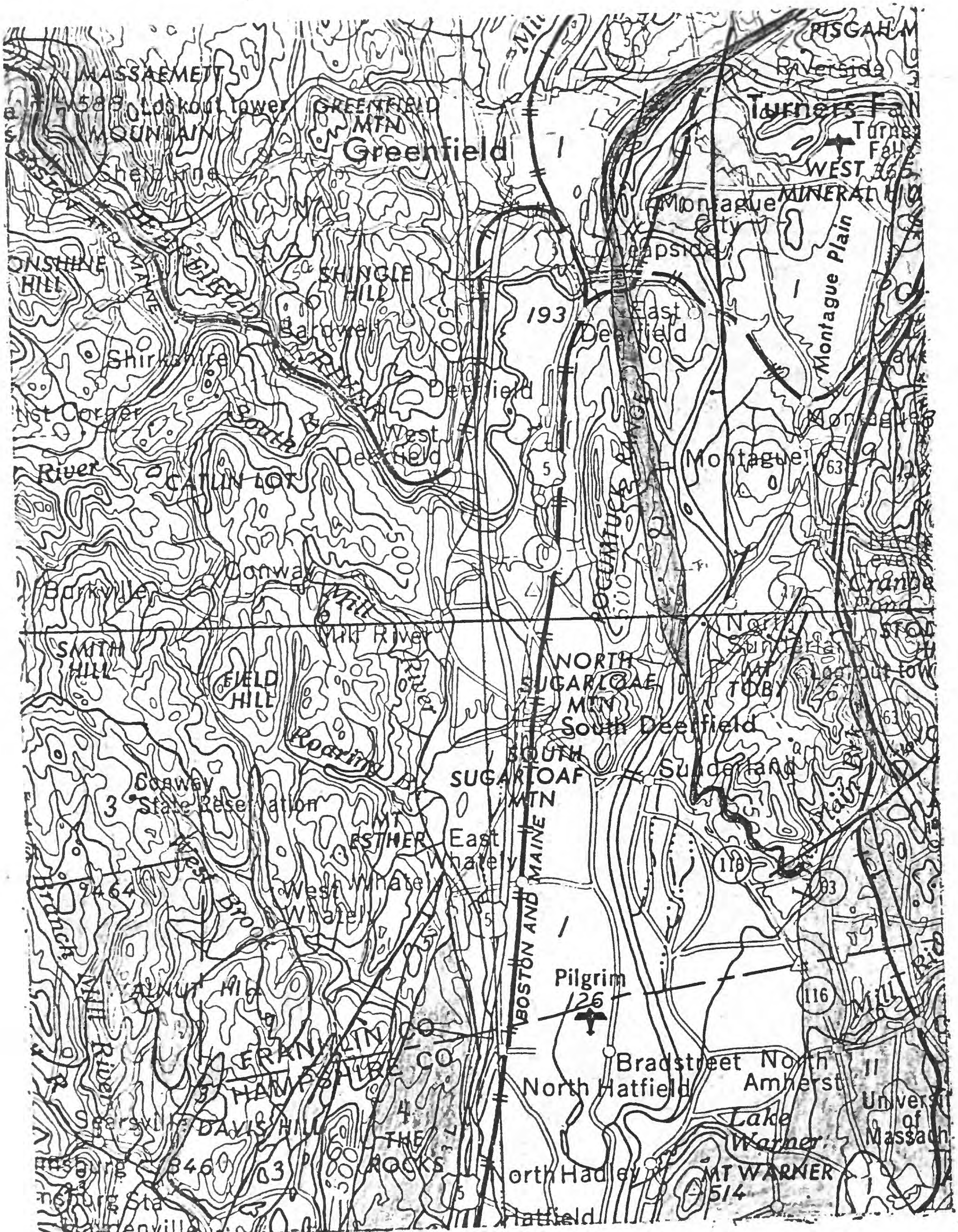

MASSAEMETT
Lookout tower
GREENFIELD MTN
MOUNTAIN
Greenfield
PISGAH
Riverside
Turners Fa
WEST MINERAL
Montague City
Cheapside
Montague Plain
SHINGLE HILL
193
East Deerfield
Deerfield
West Deerfield
Montague
CATLIN LOT
River
Conway
Mill River
SMITH HILL
FIELD HILL
NORTH SUGARLOAF MTN
South Deerfield
SOUTH SUGARLOAF MTN
Sunderland
MT TOBY
Conway State Reservation
MT ESTHER
East Whately
West Whately
BOSTON AND MAINE
Pilgrim
126
116
FRANKLIN CO
HAMPSHIRE CO
Bradstreet
North Amherst
North Hatfield
Lake Warner
DAVIS HILL
THE ROCKS
North Hadley
MT WARNER
514
Hatfield

Figure 5b

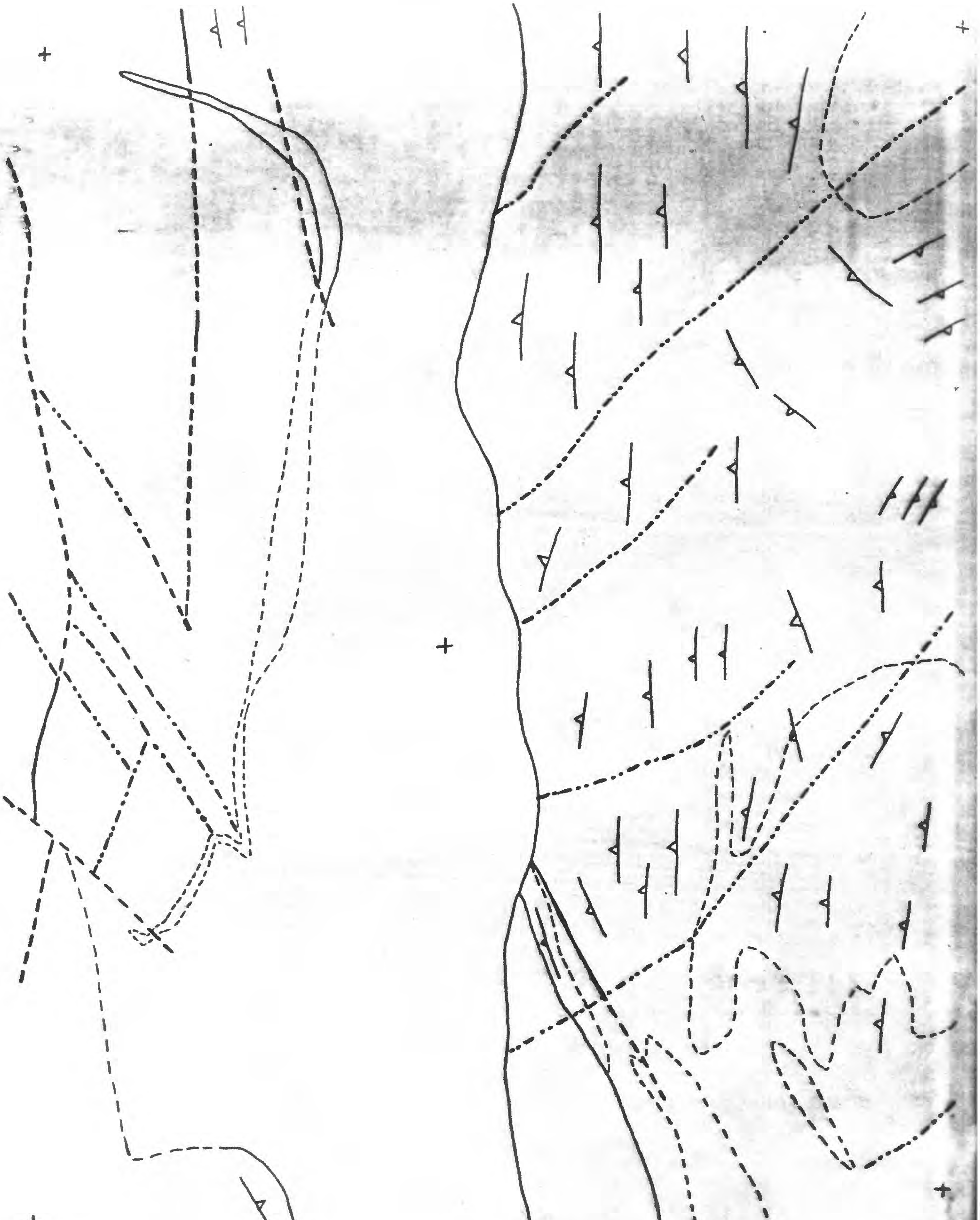


Figure 3b

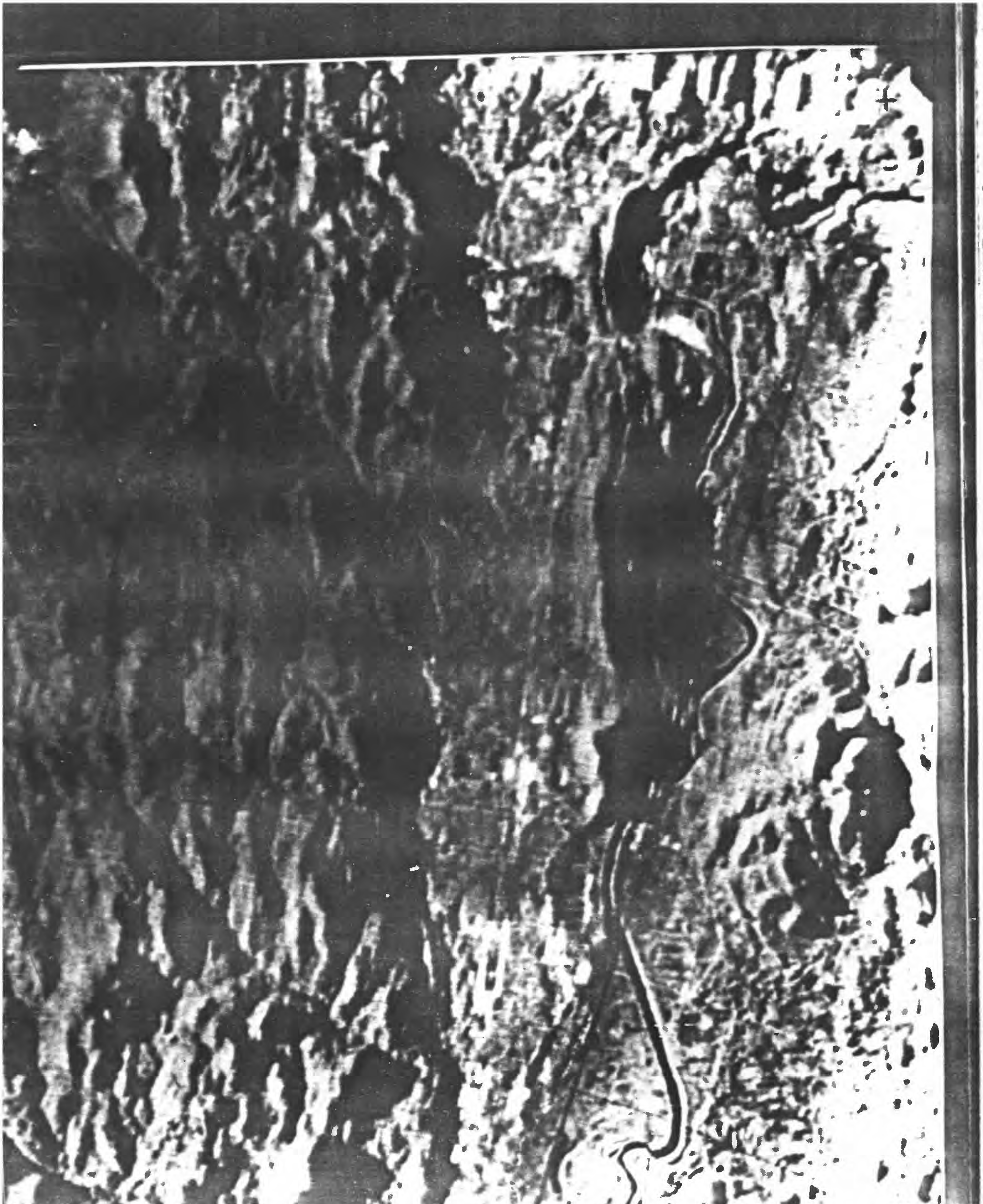


Figure 6 - Geologic structure of the Shelburn Falls, Greenfield, Williamsburg and Mount Toby Quadrangles on a non-topographic base at a scale of 1:125,000.

contact

fault with bar and bell on downthrown side

fold axis of overturned anticline

foliation

vertical foliation

bedding

joint

vertical joint

l low angle of dip - 0-30°

m medium angle of dip - 30°-60°

h high angle of dip - 60°-90°

north

0 1 2 3 4

approximate scale in kilometers

Map compiled from sources mentioned in text.

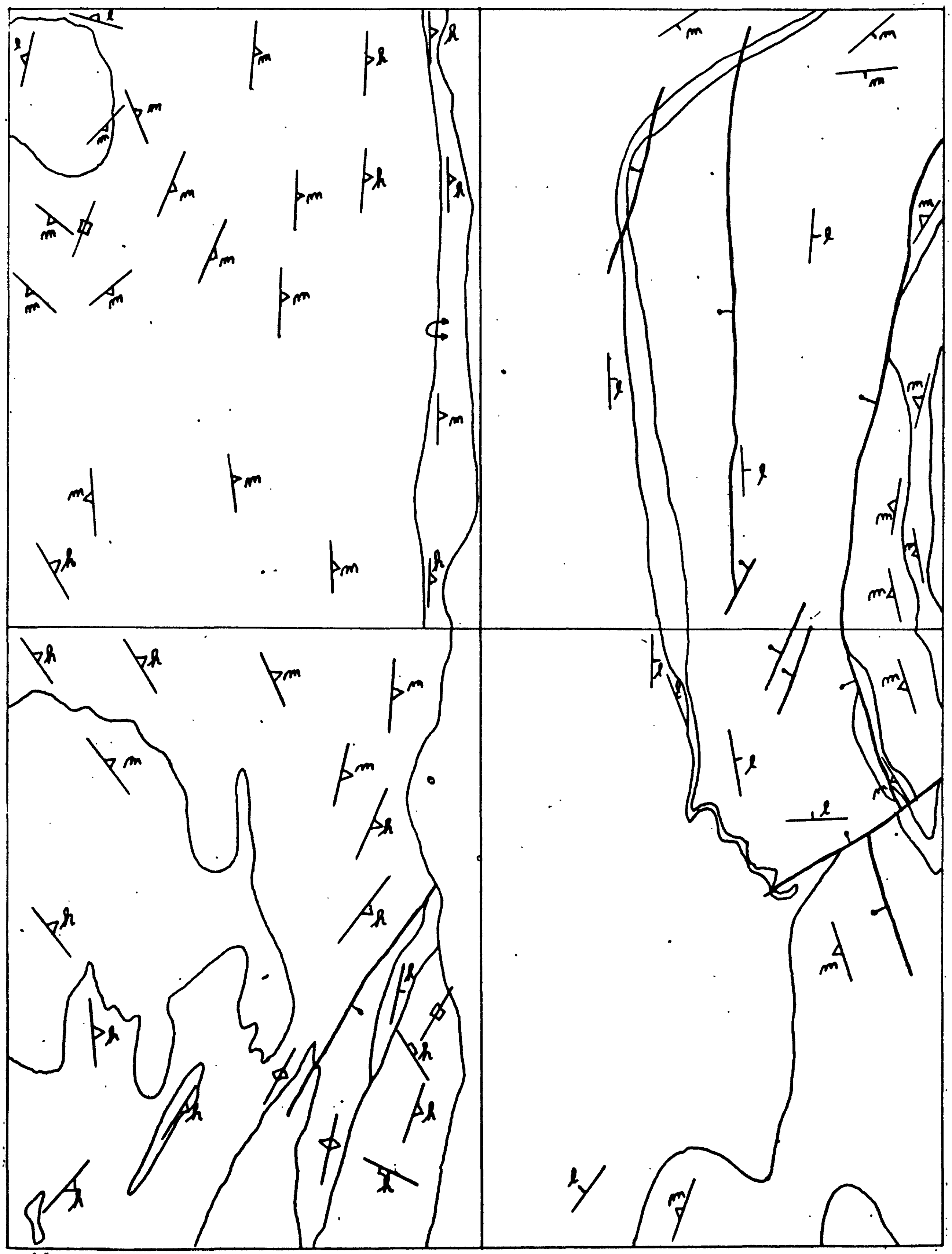


Figure 6

shows these different rock types. The trap ridge is more resistant and thus rises above the topographically lower sedimentary rocks. This change in topography is expressed on the imagery as a change in the tone and texture (due to radar shadow) of the areas underlain by these different lithologies.

The radar also shows the difference between the relatively flat lying, unmetamorphosed Triassic sedimentary rocks and the steeply dipping metamorphic rocks immediately to the west. Again there is a great enough difference between the lithologies underlying these areas to make the topography much different. And, when the topography is different the radar image is also different.

Figure 5a shows the topography of these two areas underlain by rocks with very different geologic characteristics. These different characteristics (i.e. geologic age, degree of metamorphism, angle of dip of planar features and rock type) give the topography of the two areas different characteristics. The area underlain by the Triassic rocks is flat, with little relief and no topographic lineaments. The area underlain by the older crystalline rocks is finely dissected, has much relief over a relatively small area and contains many topographic lineaments. These differences are brought out and enhanced greatly by the radar imagery (figs. 3a and 4) of the same area.

In the western half of the area shown on figure 5b there are several rock types present (as shown on the legend for figure 5b). A distinction between these rock types on the radar imagery, however, is difficult. The topographic expression of the bedrock is uniform over the area. The uniform topographic expression is due to uniform geologic characteristics of the different rock types (i.e. they are mostly layered, metamorphosed and medium to steeply dipping, crystalline rocks). Some rock types in the legend are drastically different from others, such as quartzite vs. phyllite and limestone vs. amphibolite, but such distinctive units are small, thin layers in a more uniform body of rock, and as such do not have a topographic expression visible at a scale of 1:125,000. It is apparent that for two lithologies to have a distinct enough difference in their topographic expression to be separable on radar imagery the two lithologies must also have distinct differences in their physical properties (e.g. sandstone vs. basalt or shallow dipping sandstone vs. steeply dipping schist or phyllite, as can be seen by comparing figs. 3a and 4 with fig. 5b.).

Figure 6 shows the generalized geologic structure of the area of example # 1. The mapped high angle faults seen on this figure are not clearly visible on the radar imagery (fig. 3a). Joints are also not clearly recognizable. The reason for this is the lack of topographic expression of these features. If faults, joints or any other geologic features are not reflected in the topography then they will not be interpretable on a radar image. Why these fractures (in this study the word "fracture" will mean faults, minor faults and joints because displacement is the only criteria for separating these features and that is usually not discernable on radar imagery) are not reflected in the topography is unknown except to say that they are probably minor fractures which do not control the topography here.

The mapped attitudes of bedding and foliation appear on figure 6. In the western half of the area (i.e. the area underlain by steeply dipping crystalline rocks) the strike of the bedding and foliation is parallel to the trends of the valleys and ridges as seen on the radar imagery of that area (fig. 3a). The valleys and ridges are present as a result of the differing response to erosion of the different beds or layers in the area. In this way the lithology controls the topography because of some aspects of its physical properties, namely that it is layered and steeply dipping, and because of differential erosion acting on these physical properties.

The topography here is controlled by differential erosion along planar features in the rock and this can be seen on the imagery as radar lineaments. The strike of the bedding in the Triassic sedimentary rocks is not expressed in the topography and therefore is not visible on the radar. This lack of topographic expression is due to the shallow dip of the Triassic rocks and also due to the homogeneous resistance to erosion of the different sedimentary units within the basin.

Do Glacial Features Affect the Way Bedrock Geologic Features are Reflected in the Topography?

I have pointed out some bedrock geologic features that I feel are reflected in the topography. Now it must be determined what affects the multiple glaciation of southern New England have had on the terrain and if these affects are visible on radar imagery.

Figure 7 is a generalized surficial geologic map of the Shelburn Falls (Segerstrom, 1959), Greenfield (Jahns, 1966), Williamsburg (Segerstrom, 1955) and Mount Toby (Jahns, 1951) quadrangles. It shows the positions of ice and water laid deposits, striation and groove directions and the direction of the long axes of drumlins. A comparison of figure 7 with the topography of the area (fig. 5a) reveals that ice laid drift is concentrated in the uplands and water laid drift is concentrated in the lowlands. The direction of ice movement, as inferred from drumlin and striation directions, does not have a marked correspondence to the topography as seen on figure 5a. The radar imagery does, however, show many lineaments parallel to these glacial features (the western half of figure 3a has many ridges and valleys parallel to the drumlin axes of the area). This relationship does not imply glacial control of the topography. It also does not imply that the bedrock completely controls the topography either. It does mean that the bedrock topography, existing before the advance of the ice, has a substantial affect on the deposition and erosion of the ice. And that the topography as seen on figure 5a and the radar images (figs. 3a and 4) is a predominantly bedrock controlled topography albeit etched and modified slightly by glaciation.

The scale of most glacial features, such as drumlins, ice-sculpted topography, and striations and grooves is too large to be seen on the small scale (1:125,000) of the radar imagery. Glaciation has the affect of eroding the pre-glacial weathered bedrock surface, especially along zones of weakness such as faults

Figure 7 - "Surficial" geologic map of the Shelburn Falls, Greenfield, Williamsburg and Mount Toby Quadrangles on a non-topographic base at a scale of 1:125,000.

iD - ice-deposited material, till or ground moraine.

wD - water-deposited material, clay, silt, sand and gravel.

contact

direction of glacial striation

direction of long axis of drumlin

north

0 1 2 3 4

approximate scale in kilometers

Map compiled from sources mentioned in text.

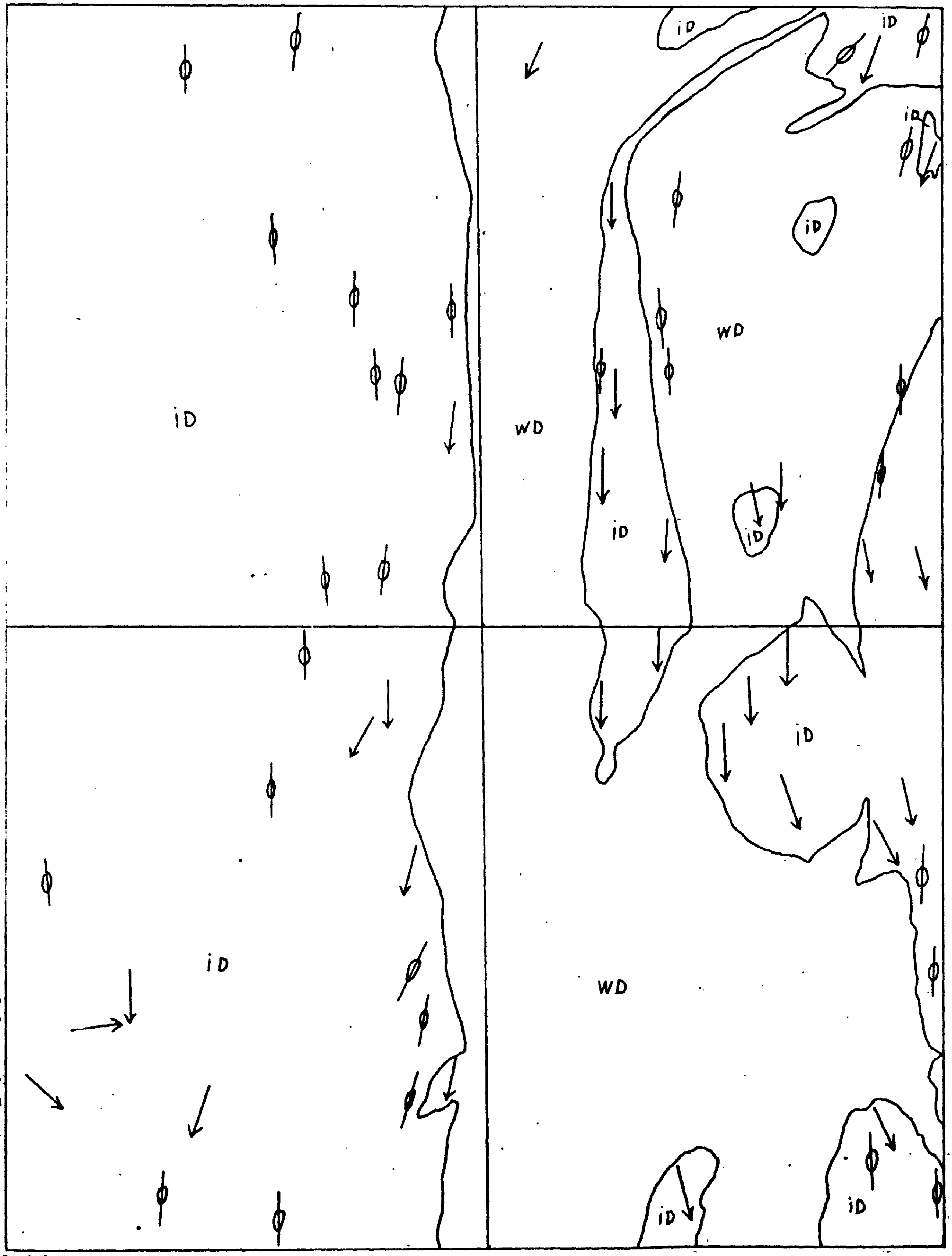


Figure 7

joints, and relatively non-resistant layers of rock within a more resistant unit, and etching out the topography in fine detail. Subsequently, glacial deposits round off topographic detail by depositing materials in the valleys and on the ridges.

What Geologic Interpretations can be Made From Radar Imagery?

Separation of lithologies was possible on figure 3a but only in cases where the physical properties of the rock, as well as the degree of layering, angle of dip of layering and degree of metamorphism, were greatly different (such as the Triassic sedimentary rocks and the older crystalline rocks to the west on fig. 5b). This distinction between lithologies is relative, however, and absolute determination of rock type on radar imagery is difficult.

The principle method used to study structure on radar imagery is to construct lineament maps. Figures 8 and 9 are radar lineament maps of the east and west looking imagery seen on figures 3a and 4. All of the lineaments present on these figures represent topographic lineaments which in turn reflect either fractures, the strike of bedding planes, the strike of foliation planes, or, less frequently, a contact between two different lithologies.

Differential erosion along these planar features in the rock creates topographic lineaments visible on radar imagery. Although the radar may distort the trend of these lineaments slightly it is not enough to seriously interfere with interpretation. The lineament maps were made by tracing the radar lineaments onto an overlay. Notice the similarity in the two lineament maps despite the fact that they were made from two opposing look

Figure 8 - Radar lineament map of the Shelburn Falls, Greenfield, Williamsburg and Mount Toby Quadrangles made from the enlarged east looking imagery, scale approximately 1:114,048.

↑ north

0 1 2 3 4

approximate scale in kilometers

+ indicates corner of quadrangle and corresponds to + on the photographs.

Lines connecting + approximate quadrangle boundaries.

Figure 8

Figure 9 - Radar lineament map of the Shelburn Falls, Greenfield, Williamsburg and Mount Toby Quadrangles made from the enlarged west looking imagery, scale approximately 1:114,048.

north

0 1 2 3 4

approximate scale in kilometers

+ indicates corner of quadrangle and corresponds to + on the photograph.

Lines connecting + approximate quadrangle boundaries.

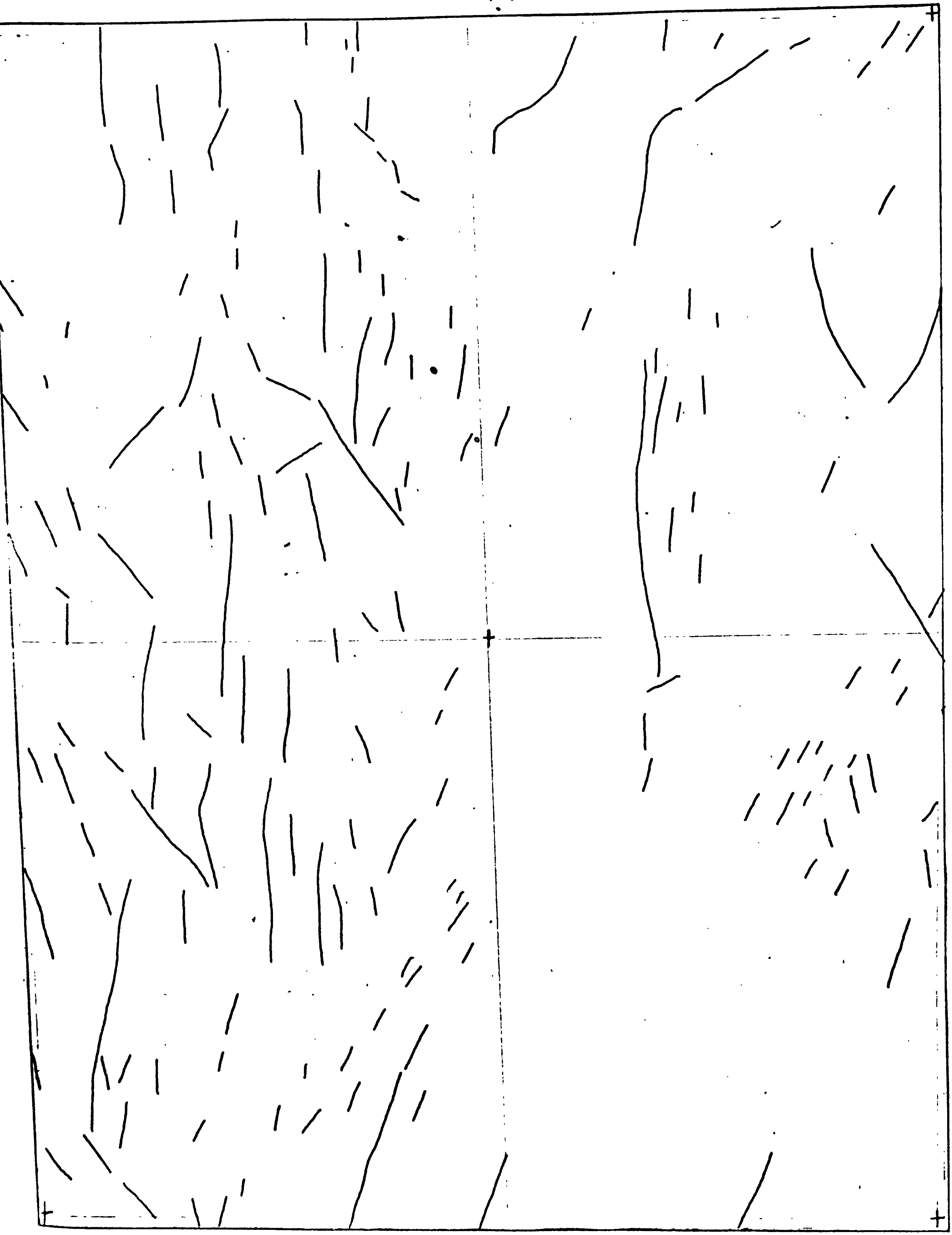


Figure 9

directions.

The lineaments of figure 8 are interpreted on figure 3b. Figure 3b also shows the lithologic contacts which were directly transferred (i.e. without interpretation) from the geologic map to an overlay on the radar imagery (fig. 3a). The contacts were transferred from one map to the other using any geographic or topographic correlations available.

The lineaments in the western part of the area were interpreted as the strike of foliation and bedding attitudes because;

1) The lineaments are parallel to the field mapped regional foliation and bedding trends.

2) The lineaments are shorter and more numerous than any other lineament group on the map.

3) The lineaments are consistent in trend over a large area (e.g. greater than 100sqkm) and do not crosscut or truncate other lineaments.

The northwest-trending lineaments in the western part of the area were interpreted as fractures for the following reasons;

1) The lineaments crosscut the trend of the regional foliation.

2) The lineaments are longer, straighter and more persistent than any other lineaments on the map.

3) In places the lineaments truncate or offset ridges.

4) The longer, straighter, crosscutting lineaments are all parallel to each other, this indicates that they may have been formed at the same time and by the same conditions of regional stress.

Interpretations concerning the surficial geology of an area based on radar imagery, and the value of these interpretations in improving the understanding of the surficial geology, are less accurate and less important than interpretations concerning the bedrock geology. Figure 7 shows the glacial geology of the area.

And, without even seeing a topographic map or a radar image of the area, it is known by basic principles that water deposited materials will be generally in the lowlands and ice deposited materials will be generally in the uplands. Also, it is known that the direction of ice flow will be more or less concordant with local topographic trends. Examination of the radar imagery (figs. 3a and 4) supports these fundamental assumptions (e.g. areas on the imagery of high elevation and relief coincide with areas shown on figure 7 showing predominantly ice deposited drift and drumlin and striation directions have a general if not specific concordance with local topographic trends, as can be noted in the western part of either radar image).

Example # 2

The area of example # 2 is located on figure 10. It covers four 7-1/2 minute quadrangles in southeastern Connecticut and equals approximately 563sqkm. Figures 11 and 12a are photographs of the north and south looking radar imagery of this area taken from the Connecticut and Rhode Island mosaics and enlarged approximately four times. Because they are photographs of a mosaic the quality is not as good as the original image strips. Figure 12a will be used for purposes of discussion and figure 11 was included so that the reader can compare two opposing look directions. The distortions present in these radar images (figs. 11 and 12a) are the same as those already discussed in the previous section.

Does Radar Imagery Accurately "See" the Topography?

Figure 13a is a topographic map of the same area shown on the two radar images, figures 11 and 12a. This topographic map has the generalized geology of the area drafted onto it (it is uncolored to allow better study of the contour lines) and is at approximately the same scale as the radar images. A comparison of the topography with the radar indicates that both look directions give an accurate picture of the terrain. Specifically, the imagery may not show certain minor features of the topography but everything visible on the radar is a real topographic feature, although it may be enhanced and slightly distorted.

Also to be noted is the marked topographic linearity visible in the northern and western parts of figure 12a. These topographic lineaments are present on the topographic map but not nearly as easily seen as on the radar image.

Are Bedrock Geologic Features Reflected in the Topography?

A map showing the lithology and major faults of the Montville

Figure 10 - Location map of the Montville, Uncasville, Niantic and New London Quadrangles in southeastern Connecticut.

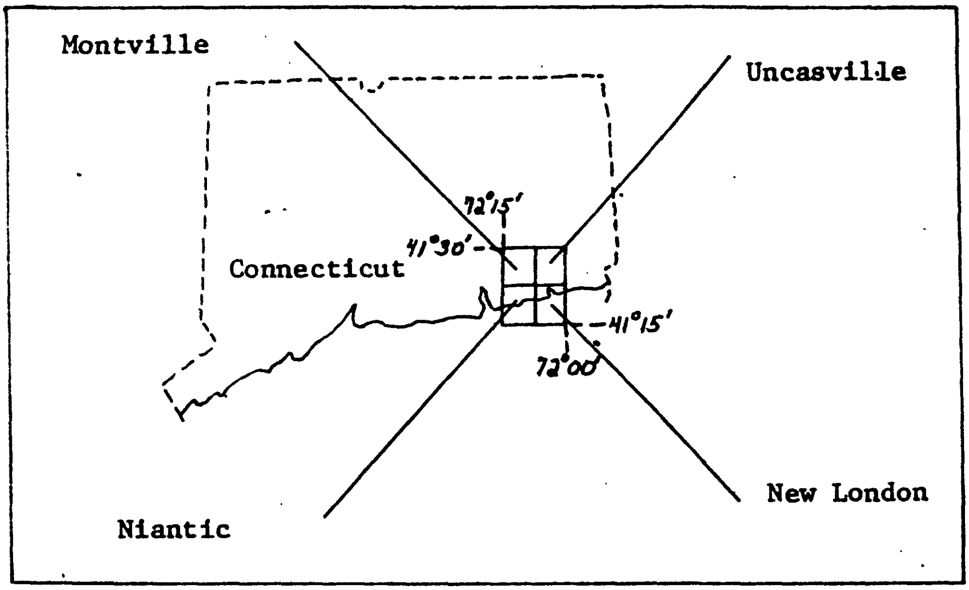

Montville
Uncasville
72°15'
41°30'
Connecticut
41°15'
72°00'
Niantic
New London

Figure 10

Figure 11 - Enlarged radar imagery of the Montville, Uncasville, Niantic and New London Quadrangles, north looking, scale approximately 1:120,384 enlarged from a scale of approximately 1:500,000. + indicates quadrangle corner (distinct white lines are not radar images).

north

0 1 2 3 4

approximate scale in kilometers

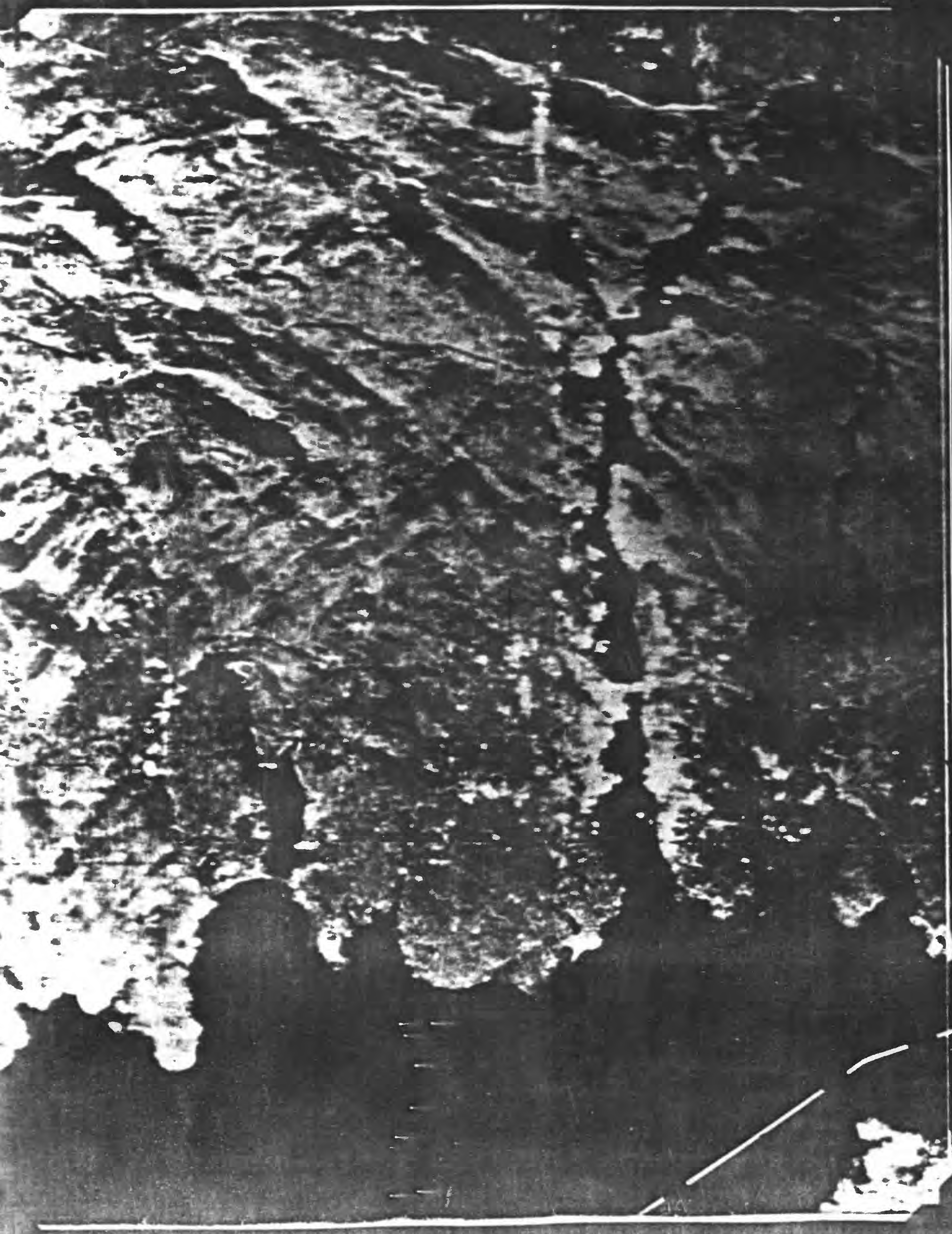


Figure 1

Figure 12a - Enlarged radar imagery of the Montville, Uncasville, Niantic and New London Quadrangles, south looking, scale approximately 1:120,384 enlarged from a scale of approximately 1:500,000 + indicates quadrangle corner (distinct white lines are not radar images).

Figure 12b - Interpretive radar-geologic map of the Montville, Uncasville, Niantic and New London Quadrangles made to overlay the enlarged south looking imagery (figure 12a), scale approximately 1:120,384.

——— contact clearly interpretable on radar imagery and also appears on mapped geology.

- - - - - contact difficult or impossible to interpret on radar imagery but appears on mapped geology.

——— fault clearly interpretable on radar imagery and also appears on mapped geology.

- - - - - fault difficult or impossible to interpret on radar imagery but appears on mapped geology.

—··—·· — fracture interpreted on radar imagery that does not appear on mapped geology.

strike and dip of bedding and/or foliation
strike interpreted from radar imagery
dip obtained from mapped geology
length of line approximates length of lineament

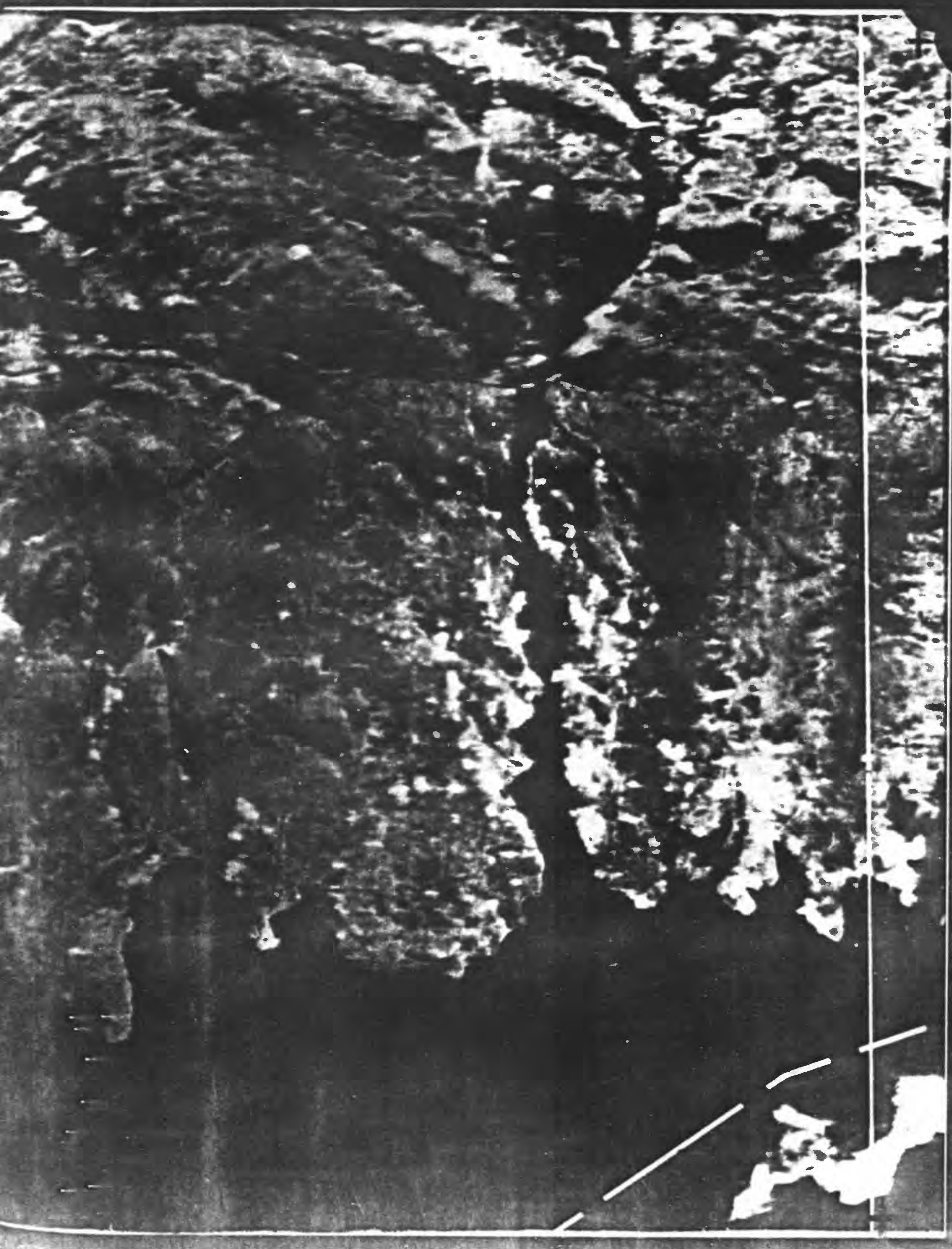
strike of vertical minor faults and joints
strike interpreted from radar imagery
dip obtained from mapped geology
length of line approximates length of lineament

+ indicates corner of quadrangle.

north

0 1 2 3 4

approximate scale in kilometers



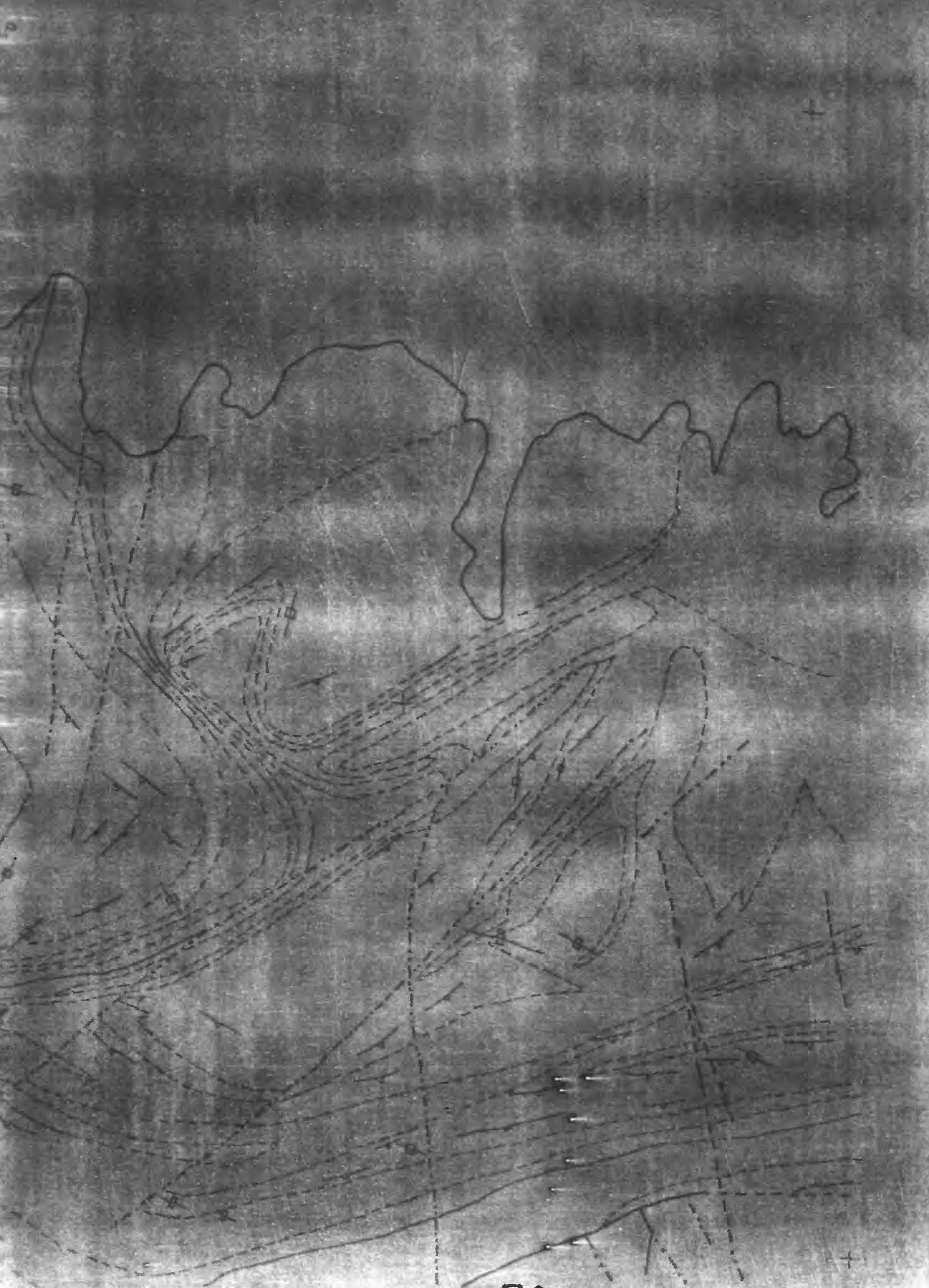


Figure 13a - Topographic map of the area of example # 2.

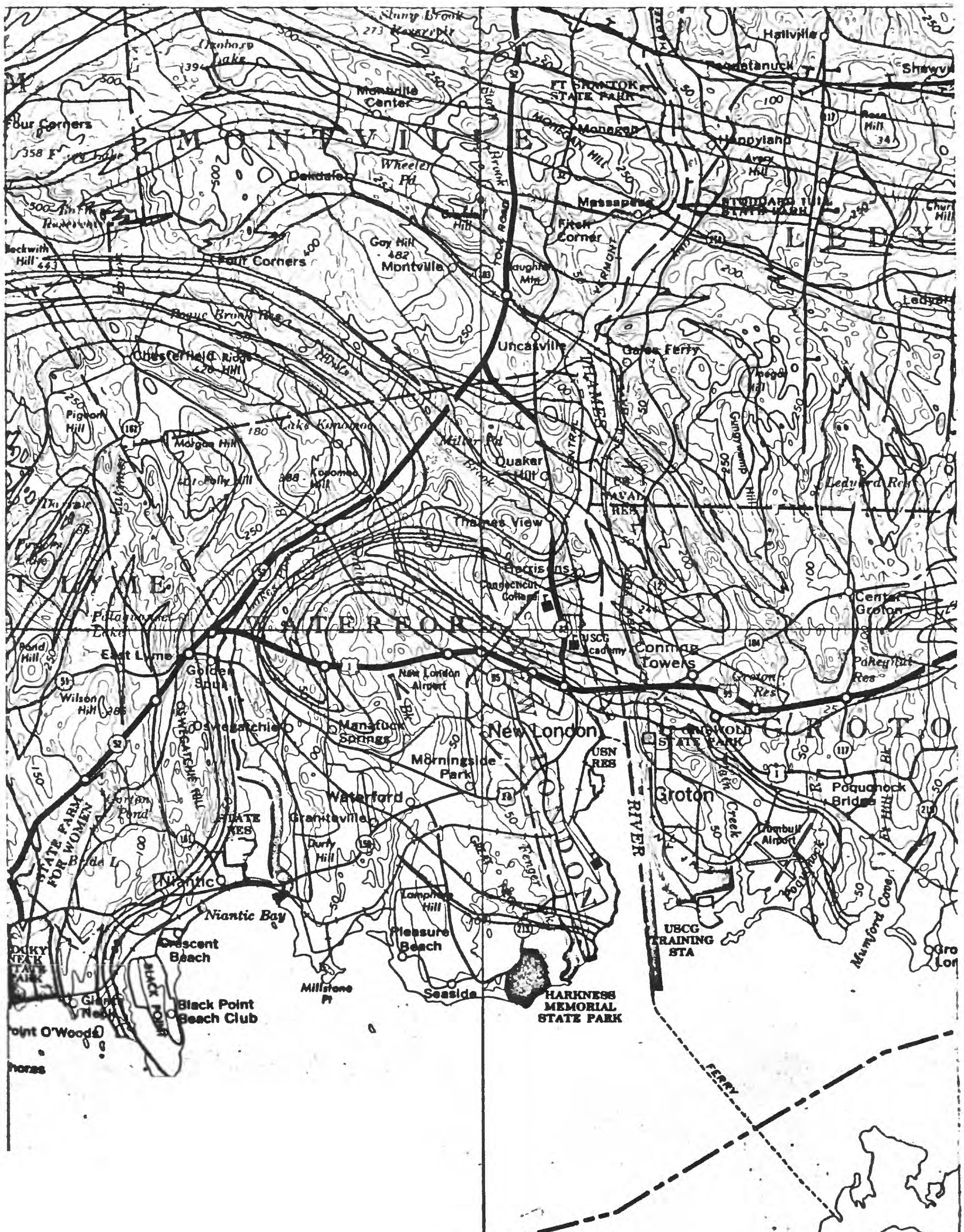

MONTVILLE
LEDYARD
LYME
WATERFORD
NEW LONDON
GROTON
Hallville
Shawville
Pequotanuck
Mohegan Center
Four Corners
Oakdale
Wheeler Pd
Monagan
Happyland
Massapeag
Fitch Corner
Gay Hill
Montville
Four Corners
Uncasville
Gales Ferry
Chesterfield
Pigeon Hill
Morgan Hill
Lake Konomoc
Miller Pd
Quaker Hill
Ledyard Res
Thames View
Harrisons
Connecticut College
USCG Academy
Conning Towers
Center Groton
East Lyme
Golden Spur
Wilson Hill
Pond Hill
New London Airport
Poheganut Res
Groton Res
Oswegatchie
Manatuck Springs
New London
Morningside Park
USN RES
Groton
Poquonock Bridge
Waterford
Graniteville
Trumbull Airport
Niantic
Niantic Bay
Crescent Beach
Black Point Beach Club
Pleasure Beach
Seaside
Millstone Pt
HARKNESS MEMORIAL STATE PARK
USCG TRAINING STA
Mumford Cove
RIVER
FERRY
STATE FARM FOR WOMEN
Point O'Woods

Figure 13a

(Goldsmith, 1967a), Uncasville (Goldsmith, 1967b), Niantic (Goldsmith, 1967c) and New London (Goldsmith, 1967d) quadrangles is shown on figure 13b. The geologic structure of the same area is shown on figure 14.

The question of whether lithology is reflected in the topography can be answered only after some definitions and background material have been discussed. As was seen in example # 1 only those lithologies that were both chemically and structurally distinct had distinct topographic expression. In the case of example # 2 all the rock types present are either Precambrian or lower Paleozoic crystalline rocks, thus there is not the radical difference in lithology found in example # 1. Yet when figure 12a is compared to the lithologic map (fig. 13b) it is clear that the topography, as seen on the radar, has some definite correspondences to the lithology.

The first thing to be mentioned in determining exactly what correspondence exists between lithology and topography (and why it exists) is that the lithologic contacts seen on figure 13b are a geologists interpretation of where the lines should be drawn. Figure 12a is an image of the terrain as erosion and subsequent glacial deposition has left it. Erosional processes may separate and divide lithologies differently than a geologist would.

Lithology, in the case of example # 2, has topographic expression in some places and not in others. For example the northern part of the study area has many ridges and valleys corresponding to some of the lithologic units seen on figure 13b. The southern half of the area, however, as seen on the radar image

Figure 13b - "Geologic" map of the Montville, Uncasville, Niantic and New London Quadrangles showing lithologic contacts and faults on a topographic base at a scale of 1:125,000 and a contour interval of 50ft.

PRE-PENNSYLVANNIAN

1 -fine to medium grained gneissic granite, fine grained poorly foliated granite,medium grained biotite granite gneiss, medium to coarse grained biotite,quartz monzonite gneiss, medium grained gneissic hornblende, biotite granite.

ORDOVICIAN OR OLDER

2 -biotite schist and gneiss with sillimanite and garnet,layered hornblende,biotite gneiss and amphibolite, graphite,pyrite, sillimanite bearing biotite,quartz,feldspar gneiss.

3 -sillimanite,garnet schist and gneiss, sulfide bearing garnet, sillimanite gneiss with lenses of pegmatite and thin layers of calc-silicate gneiss and amphibolite.

4 -hornblende andesine to labradorite gneiss and amphibolite.

5 -medium to coarse grained, layered to massive, biotite,hornblende, quartz,plagioclase gneiss with small lenses and layers of amphibolite,fine grained,biotite,quartz,microcline,albite gneiss.

6 -interlayered granodioritic gneiss and amphibolite with thick layers of granite gneiss,medium to fine grained, massive gneissic granodiorite locally quartz monzonite.

7 -layered biotite,quartz,orthoclase gneiss,calc-silicate gneiss and amphibolite, garnetiferous quartz,sillimanite,biotite,andesine gneiss.

8 -layered,fine to medium grained, biotite,quartz,plagioclase gneiss, hornblende gneiss and minor amphibolite.

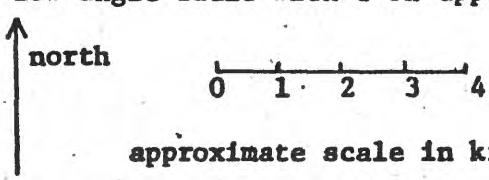
CAMBRIAN

9 -thin bedded, biotite,feldspar quartzite,biotite,feldspar,quartz schist, calc-silicate quartzite,calcareous schist, garnet,sillimanite, biotite,quartz,feldspar gneiss and schist,hornblende,biotite, quartz,plagioclase gneiss.

——contact

——high angle fault with bar and bell on downthrown side

——low angle fault with T on upper plate



approximate scale in kilometers

Map and explanation compiled from sources mentioned in text.

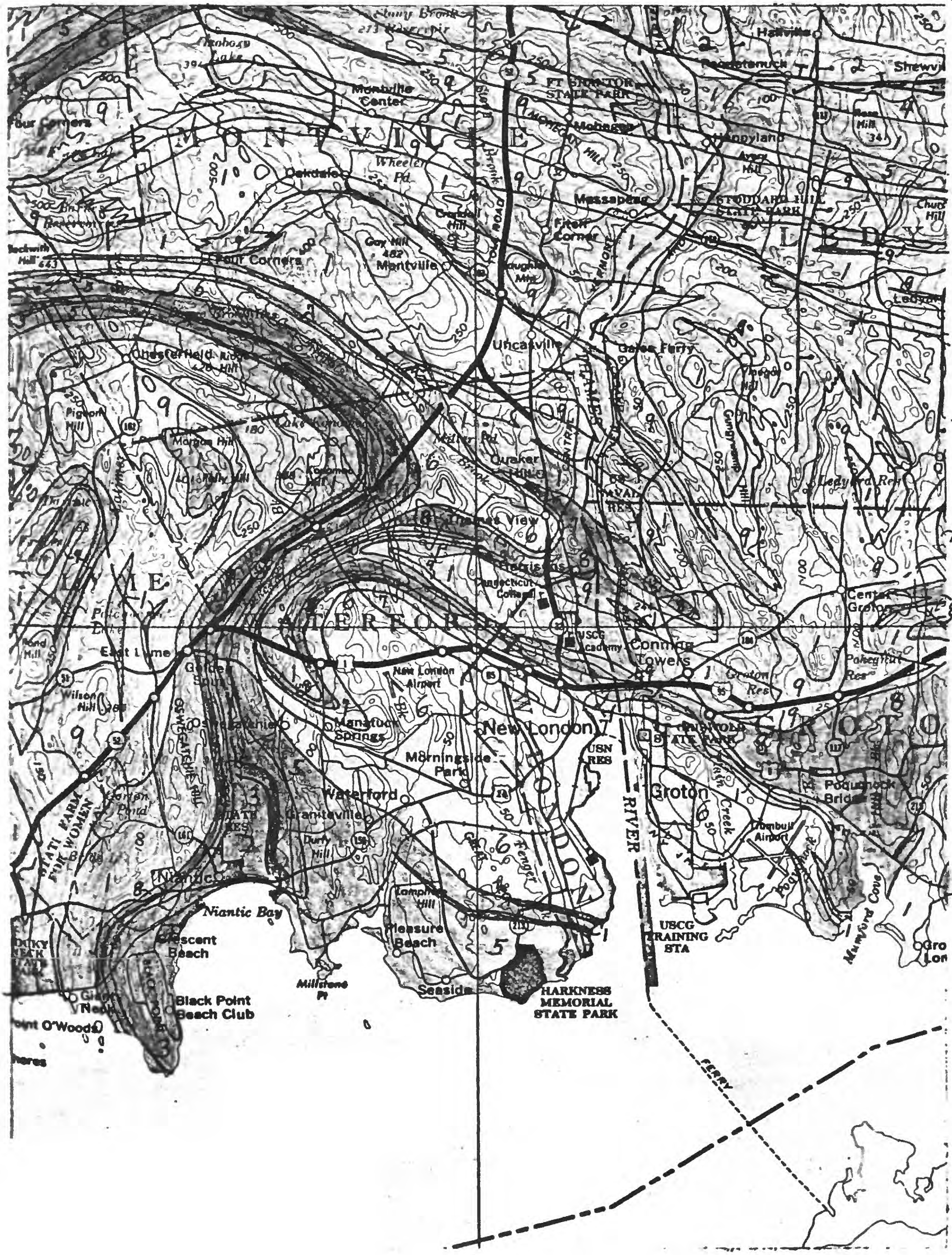

Montville Center
Four Corners
Oakdale
Montville
Uncasville
Mohegan
Massapeag
Fitch Corner
Gales Ferry
Happyland
Hallville
Shewville
Ledyard
Chesterfield
Morgan Hill
Pigeon Hill
Thames View
Quaker Hill
Connecticut College
USCG Academy
Conning Towers
Center Groton
East Lyme
Golden Spur
Wilson Hill
Oswegatchie
Manatuck Springs
New London Airport
New London
Morningside Park
Waterford
Graniteville
Niantic
Niantic Bay
Crescent Beach
Black Point Beach Club
Point O'Woods
Millstone Pt
Pleasure Beach
Seaside
HARKNESS MEMORIAL STATE PARK
USN RES
Groton
Trumbull Airport
USCG TRAINING STA
Poquonock Bridge
Mumford Cove
FERRY
RIVER
STATE FARM FOR WOMEN
Uncas Pond
Gungywamp

Figure 13b

Figure 14 - Geologic structure of the Montville, Uncasville, Niantic and New London Quadrangles on a non-topographic base at a scale of 1:125,000.

contact

high angle fault with bar and bell on downthrown side

low angle fault with T on upper plate

fold axis of overturned anticline

fold axis of overturned syncline

foliation

vertical foliation

bedding

joint

vertical joint

north

0 1 2 3 4

approximate scale in kilometers

l low angle of dip - 0-30°

m medium angle of dip - 30°-60°

h high angle of dip - 60°-90°

Map compiled from sources mentioned in text.

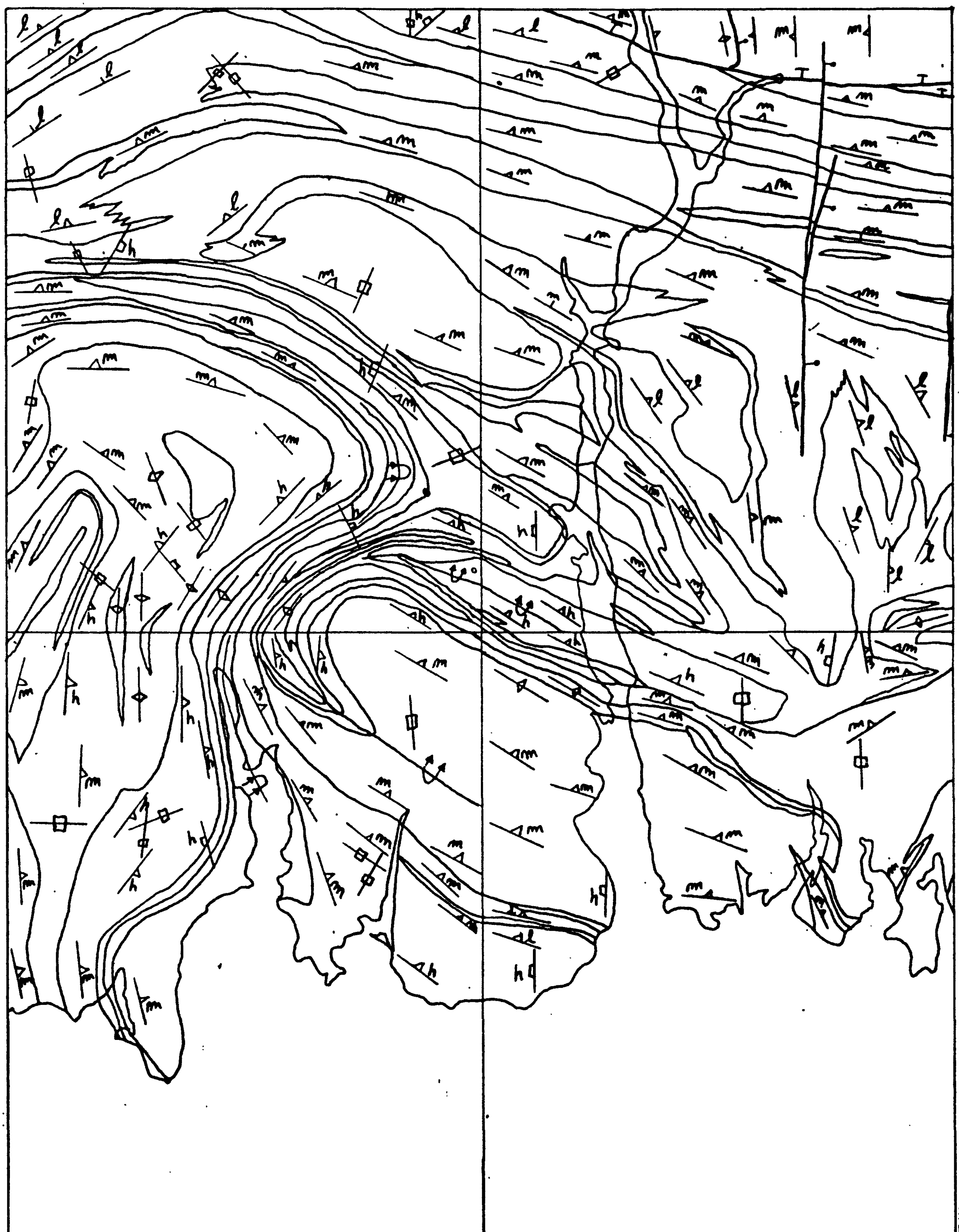


Figure 14

(fig. 12a) shows very little relation between topography and lithology. Even where the topography has excellent lithologic correlation this correlation does not extend over the entire area underlain by a particular rock type. Units continuing from the northeast part of figure 13b to the northwest part do not clearly do so on the radar image (fig. 12a).

In summary it appears that in some places lithology is reflected in the topography and in some places it is not. A particular rock type with very good topographic expression in one place may have little or no topographic expression in others. The pre-Pennsylvannian gneissic granite in the northern part of the Uncasville quadrangle stands out in a topographically distinct ridge trending northwest. The same gneissic granite further south in the Uncasville and New London quadrangles has no clear topographic expression. Some reasons for this non-uniform topographic expression of lithologies are;

1) Erosion of areas underlain by the same rock type or of contacts between units of varying resistance may not take place uniformly in all locations.

2) Glacial deposits vary in thickness and in the southern part of the area they are thicker than in the northern part, and thus they reduce the bedrock relief of the area.

3) Geologic structure (i.e. faults and folds) can affect the topographic expression of a rock unit. The granite gneiss in the northern part of the Uncasville quadrangle that has good topographic expression is also in close proximity to a large east-west trending fault. The granite gneiss further south is not close to such a large, regionally important fault and does not have the good topographic expression either. The developement of good foliation and bedding is also important. A well foliated, steeply dipping member or bed of a particular unit will have much better topographic expression than a less well foliated or more shallow dipping part of the same lithologic unit.

Figure 14 shows the geologic structure of the area of example # 2. Bedding and foliation, and fractures are two important elements of geologic structure that can be seen on radar imagery. Fractures in this study will include both faults and joints. This is done for several reasons; first, at the scale of radar imagery individual joints are not seen, rather swarms or groups of joints create topographic lineaments. Second, the distinction between faults and joints on any remote sensor is difficult. And third, in many cases the joint swarms that are visible on the imagery as lineaments are joints that are close to, parallel to and caused by faulting.

By comparing figure 14 to the radar imagery of the same area (fig. 12a) it is clear that many of the bedding and foliation attitudes are reflected in the topography as topographic lineaments (and therefore radar lineaments). The southern part of the Montville quadrangle and the northern part of the Niantic quadrangle illustrate this fact well. Differential erosion acted on the bedding and foliation planes to produce the topography seen. Again, as with lithology, there appears to be some areas where the correlation between bedding and foliation attitudes and the topography is better than others. Important factors deciding whether the topography will reflect structural attitudes or not are very similar to those factors that are important in deciding whether lithology will be reflected in the topography. The dip of the bedding and foliation may be shallow, as in the central and southern parts of the Uncasville quadrangle, and thus inhibit differential erosion from acting. This prevents good radar expression of these geologic features (figs. 11 and 12a). It should be mentioned here that if the look direction is either parallel to or near parallel to (within 5°) a linear topographic feature that feature will become very difficult to see (this fact will be shown in detail in example # 3).

The thrust fault in the northern part of the Uncasville quadrangle has excellent topographic expression in the western extent of it but not very good expression at all in the eastern extent of it. The two high angle faults in the western half of the Uncasville quadrangle are very poorly expressed. The fact that the look direction here is almost parallel to the strike of these high angle faults is responsible for their invisibility on the radar. The absence of excellent topographic expression throughout the entire length of the thrust fault in the northern part of the Uncasville quadrangle is due in part to the low angle of dip.

Do Glacial Features Affect the Way Bedrock Geologic Features are Reflected in the Topography?

Figure 15 is a generalized surficial geologic map of the Montville (Goldsmith, 1962a), Uncasville (Goldsmith, 1960), Niantic (Goldsmith, 1964) and New London (Goldsmith, 1962b) quadrangles.

A comparison of figure 15 with figure 12a (the radar imagery of the area of example # 2) reveals that there is some correspondence between the depositional and erosional aspects of glaciation and the topography. In the northern part of the radar image there is a system of northwest trending ridges and valleys. Alternating areas of high and low elevation can be seen on the image as

Figure 15 - "Surficial" geologic map of the Montville, Uncasville, Niantic and New London Quadrangles on a non-topographic base at a scale of 1:125,000.

$\boxed{\text{iD}}$ - ice-deposited material, till or ground moraine.

$\boxed{\text{wD}}$ - water-deposited material, clay, silt, and sand and gravel.

——— contact

← direction of glacial striation

↑ north

0 1 2 3 4

approximate scale in kilometers

Map compiled from sources mentioned in text.

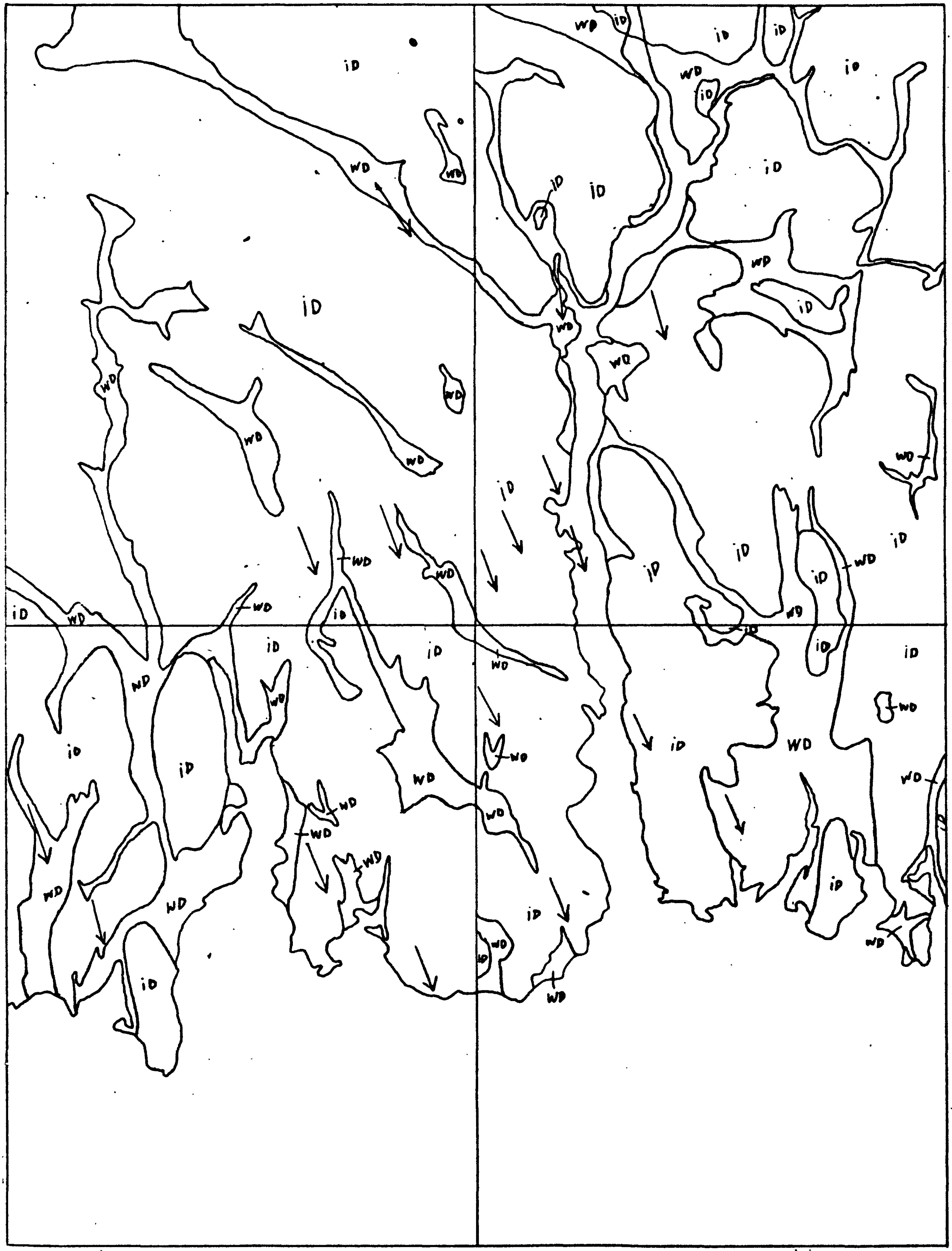


Figure 15

alternating bands of light and dark tone with the low areas indicated by the dark tones (this is because the ridges, when illuminated by radar energy, shadow the valleys). On figure 15 it can be seen in this same area that belts of water deposited material coincide with the low areas of the topography. Ice deposited material is found in the high areas of this region. In general, over the entire area of example # 2, places of low elevation coincide with areas of water deposited glacial drift and areas of high elevation coincide with areas of ice deposited glacial drift.

Glacial striations and grooves seen on figure 15 also have some degree of topographic correspondence. The radar image of the area shows some lineaments (especially in the region just north of the intersection of the four quadrangles) that are approximately parallel to the direction of glacial movement as indicated by the striations. The striations themsleves are far too small to be seen on the imagery but what is important here is ice sculpted topography, streamlined in the direction of ice movement. The many mapped striations show the true ice movement direction. Therefore lineaments seen on the imagery, parallel to striations mapped in the field, are not those striations but larger scale features created by the same type of processes as the striations and approximately in the same place. For the most part, however, there is little correlation between this erosional aspect of glaciation and the topography of this area as seen on the radar imagery (fig. 12a).

<u>What Geologic Interpretations Can be Made From Radar Imagery?</u>

Figure 12b has the lithologic contacts seen on figure 13b drafted onto an overlay of the radar imagery of the same area. The contacts were directly transfered without any interpretation using topographic, geographic and cultural reference points where ever possible. In many instances, such as in the southern part of the Montville quadrangle and the northern part of the Niantic quadrangle, contacts shown by a dashed line could have been interpreted otherwise by a different observer. Here there are many lineaments which are very near parallel to and coincident with field mapped lithologic contacts. They are also near parallel to and coincident with structural attitudes. To interpret such topographic features as expressions of specific lithologic contacts is not valid because;

1) There are too many lineaments in too small an area to be sure which one is related to any given field mapped contact. Even assuming that these clustered lineaments are caused by lithologic contacts and not fractures is risky.

2) There exists the possibility that lineaments created by erosion (separating two lithologies by their different resistant to erosion) and lines drawn by a geologist separating two lithologies may not occur in the same place. The physical properties of a rock type are what determines its resistance to erosion and also (most often) what makes them geologically distinct.

3) A fracture lineament, close to or coincident with the contact may cause the topographic expression. In this case the contact would have a topographic expression but that expression would not be due to the fact that two lithologies bordered each other here.

Figure 16 and 17 show the radar lineaments of the north and south looking imagery of the area of example # 2. The lineaments on figure 17 are interpreted and shown on figure 12b. All the lineaments represent some planar geologic feature which becomes a linear topographic feature at the surface of the earth.

Figure 16 - Radar lineament map of the Montville, Uncasville, Niantic and New London Quadrangles made from the enlarged north looking imagery, scale approximately 1:120,384.

north

0 1 2 3 4

approximate scale in kilometers

+ indicates corner of quadrangle and corresponds to + on the photographs.

Lines connecting + approximate quadrangle boundaries.

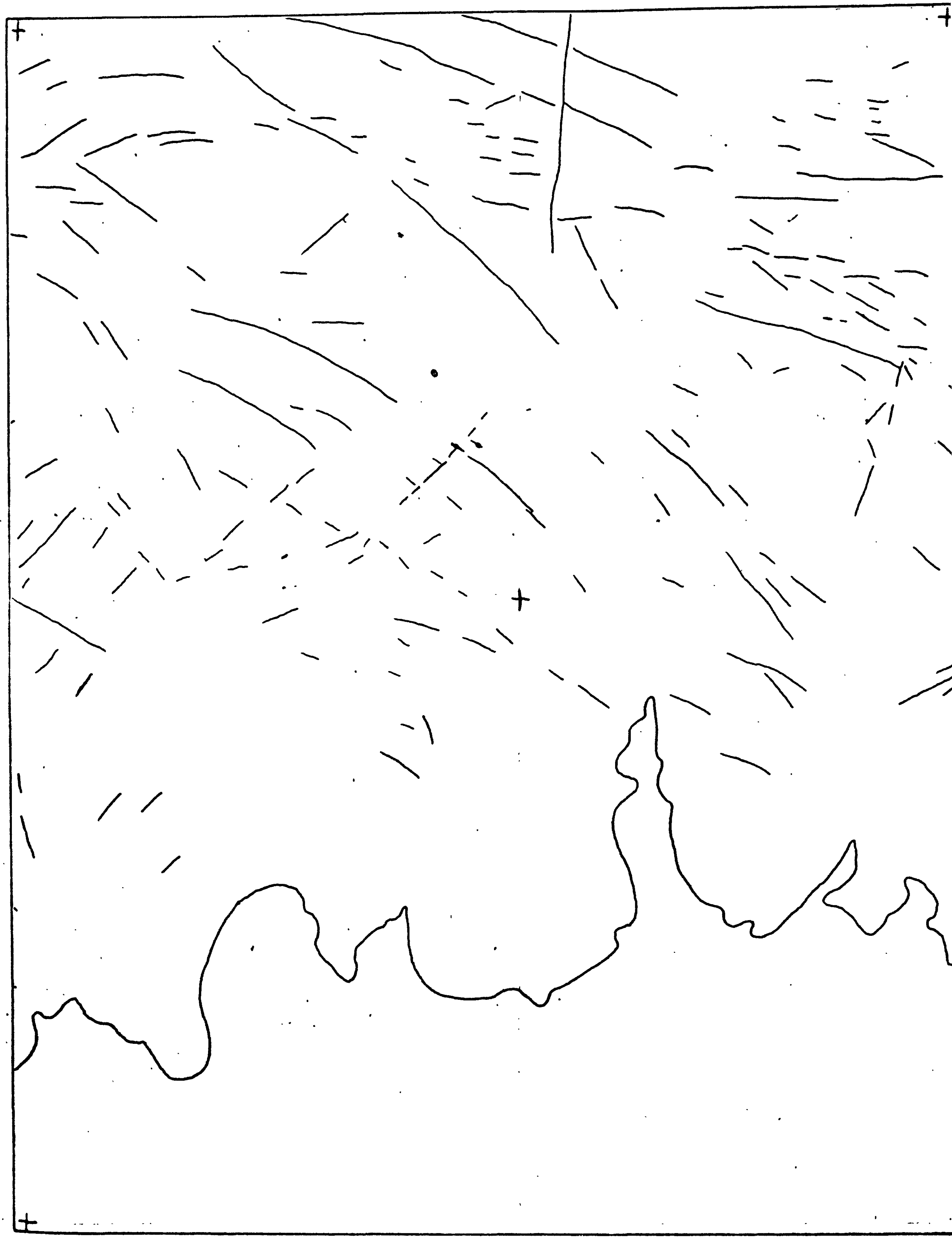


Figure 16

Figure 17 - Radar lineament map of the Montville, Uncasville, Niantic and New London Quadrangles made from the enlarged south looking imagery, scale approximately 1:120,384.

north

0 1 2 3 4

approximate scale in kilometers

+ indicates corner of quadrangle and corresponds to **+** on the photographs.

Lines connecting + approximate quadrangle boundaries.

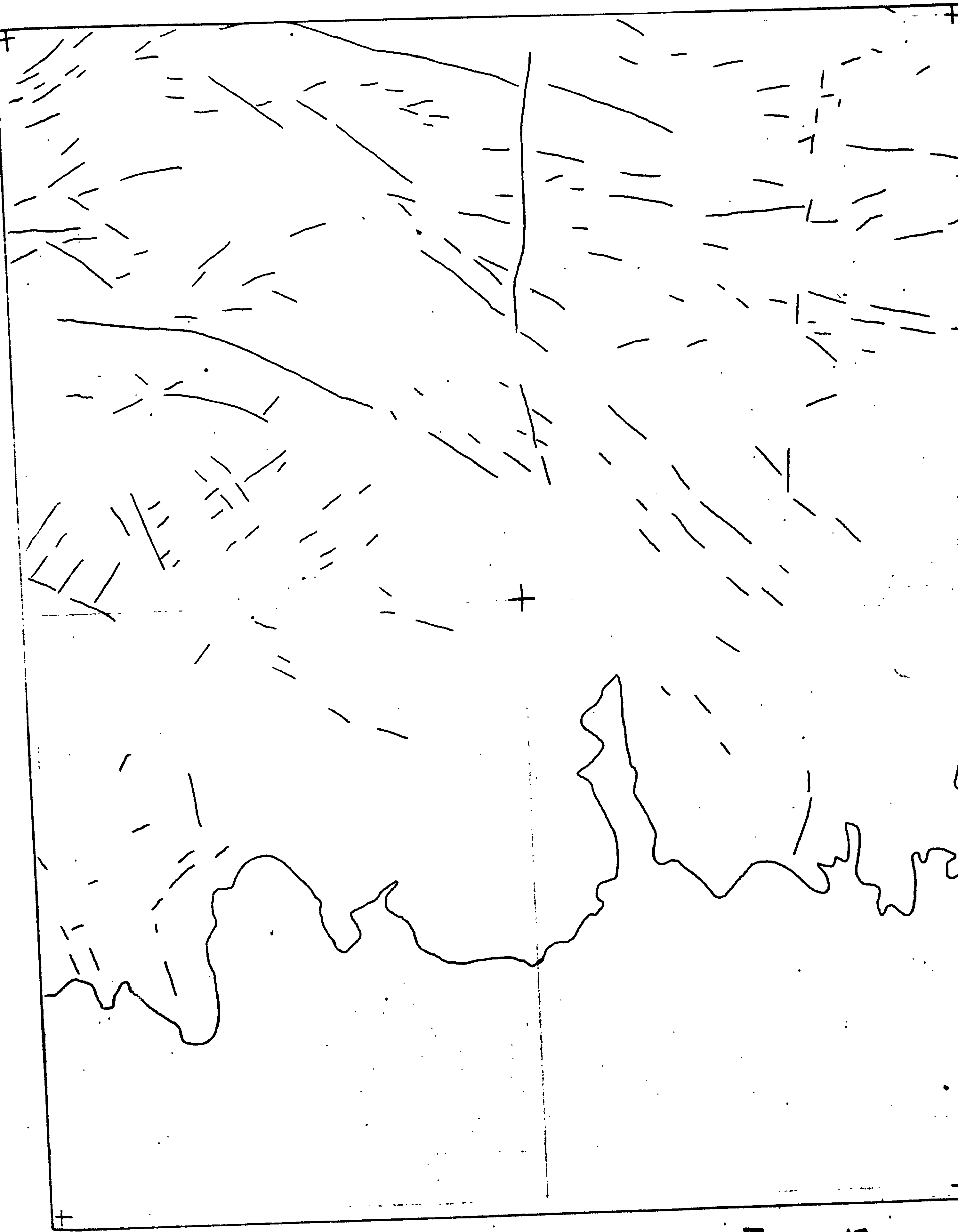


Figure 17

The lineaments interpreted as the strike of bedding and foliation were interpreted that way because of the following;

1) The lineaments are parallel to and coincident with field mapped structural attitudes.

2) The lineaments are shorter, more numerous and more regionally consistent than any other lineaments or lineament groups present.

3) The lineaments do not crosscut other lineaments.

4) The magnitude of the tonal contrast that creates bedding and foliation lineaments is not as great as the tonal contrast caused by fracture lineaments.

Lineaments interpreted as joints (joints can not usually be interpreted but here, mostly because of abundant field mapped data, they could) were done so because;

1) They parallel and are coincident with field mapped joints.

2) They crosscut the trend of the regional foliation.

3) They are shorter and have more of a criss-cross nature than lineaments interpreted as being caused by faults.

4) They show no obvious relative displacement.

Lineaments interpreted as fractures (the term fracture includes joints, in this case they are probably faults but since no displacement can be shown they must be called fractures) also crosscut the regional foliation but they are longer, straighter and more consistent over large areas than crosscutting lineaments interpreted as joints. If not for the field mapped data I feel that the recognition of joints as opposed to faults on radar imagery is difficult.

Interpreting glacial geological information, either on the nature of the deposits or on the direction of ice movement, from radar imagery is very difficult in this area and at this scale.

On figure 12a no lineaments are obviously parallel to striation directions as seen on figure 15. Furthermore there is no tone and/or texture patterns that indicate whether the glacial drift underlying that particular tone or texture is water deposited or ice deposited.

The reason that striations, grooves and ice sculpted topography are not visible on radar imagery is the scale of those features. They are simply too small to be seen on a radar image. Water deposited glacial drift has very little topographic expression of its own (Flint, 1930) and ice deposited glacial drift has only slightly more of a topographic expression than water deposited drift but still not enough relative to the bedrock relief (in most areas) to be visible on radar imagery.

Example # 3

Area # 3 was chosen to illustrate an example of orthogonal look direction coverage. It lies in an area of overlap between north and east looking mosaics in Connecticut and Massachusetts. The area is located on figure 18 and it covers four 7-1/2 minute quadrangles in south-central Massachusetts and north-central Connecticut and equals approximately 563sqkm.

Figure 19 was photographed from the Connecticut and Rhode Island north looking imagery and figure 20a was taken from the Massachusetts east looking imagery. The difference between these two images of exactly the same terrain is clearly observed on these figures.

Does Radar Imagery Accurately "See" the Topography?

The topography of the area of example # 3 is shown on figure 21a. If the topography is compared to figure 20a, the east looking radar imagery of the area, a good correspondence between the two is present. But if the topography is compared to figure 19, the north looking imagery of the area, a poor correspondence is observed. The reason for this difference between the two radar images is look direction and its relation to the regional scale topographic trends. The topography of this area is predominantly north to slightly northeast trending. This means that the north looking imagery is parallel or near parallel to the trend of the topographic lineaments and, conversely, the east looking imagery is near orthogonal to the topographic trend. Since a look direction parallel to any topographic lineament subdues that lineament

Figure 18 - Location map of the Palmer, Warren, Monson and Wales Quadrangles in south-central Massachusetts and north-central Connecticut.

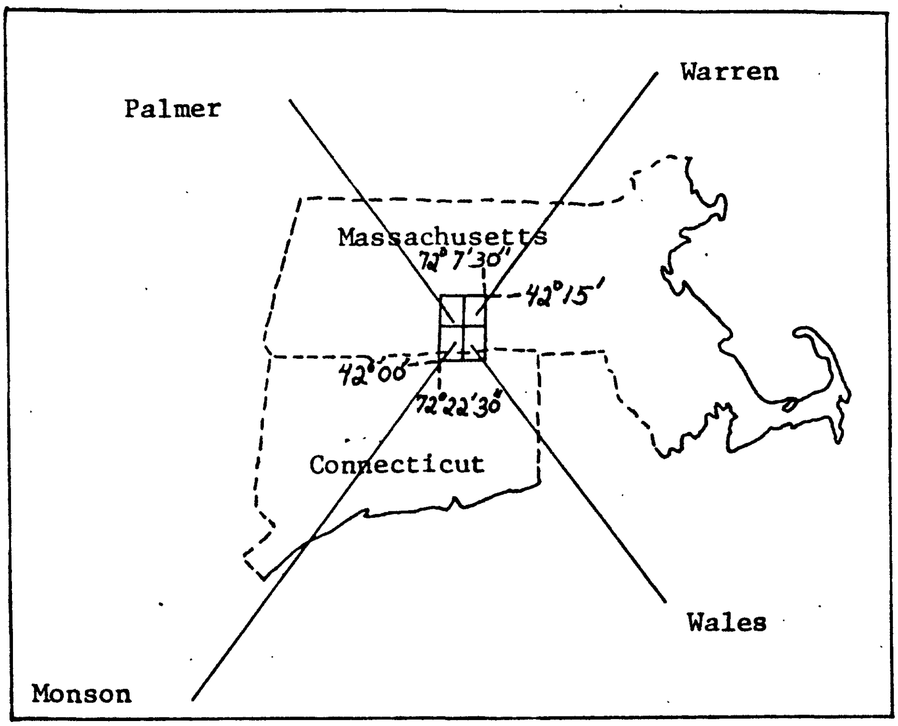

Palmer
Warren
Massachusetts
72° 7'30"
42°15'
42°00
72°22'30"
Connecticut
Wales
Monson

Figure 18

Figure 19 - Enlarged radar imagery of the Palmer, Warren, Monson and Wales Quadrangles, north looking, scale approximately 1:120,384 enlarged from a scale of approximately 1:500,000. + indicates quadrangle corner (distinct white lines are not radar images).

↑ north

0 1 2 3 4

approximate scale in kilometers

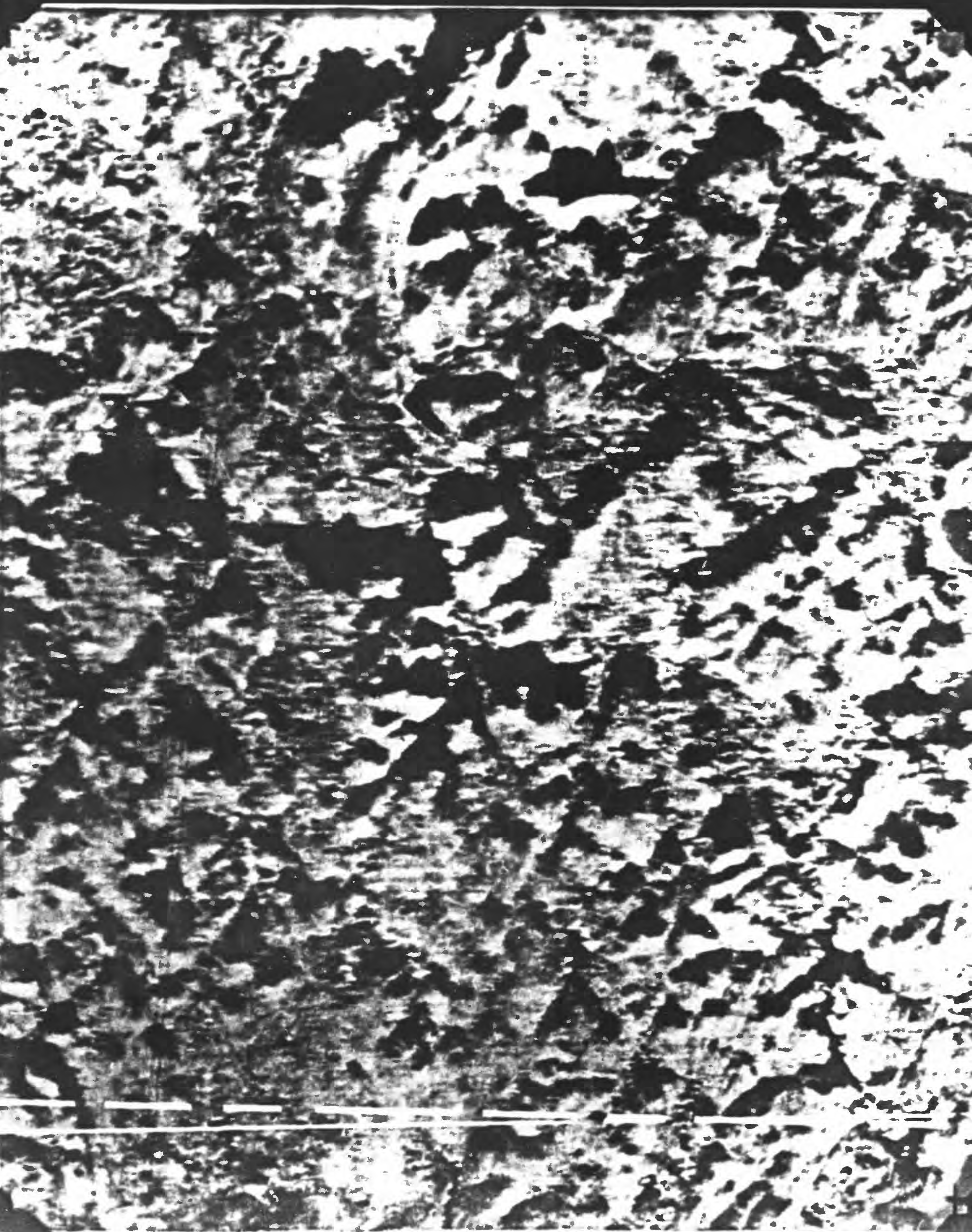


Figure 19

Figure 20a - Enlarged radar imagery of the Palmer, Warren, Monson and Wales Quadrangles, east looking, scale approximately 1:125,000 enlarged from a scale of approximately 1:500,000. + indicates quadrangle corner.

Figure 20b - Interpretive radar-geologic map of the Palmer, Warren, Monson and Wales Quadrangles made to overlay the enlarged east looking imagery (figure 20a), scale approximately 1:125,000.

contact clearly interpretable on radar imagery and also appears on mapped geology.

contact difficult or impossible to interpret on radar imagery but appears on mapped geology.

fault clearly interpretable on radar imagery and also appears on mapped geology.

fault difficult or impossible to interpret on radar imagery but appears on mapped geology.

fracture interpreted on radar imagery that does not appear on mapped geology.

strike and dip of bedding and/or foliation
strike interpreted from radar imagery
dip obtained from mapped geology
length of line approximates length of lineament

strike of vertical minor fault (includes joints)
strike interpreted from radar imagery
dip obtained from mapped geology
length of line approximates length of lineament

+ indicates corner of quadrangle.

north

0 1 2 3 4

approximate scale in kilometers

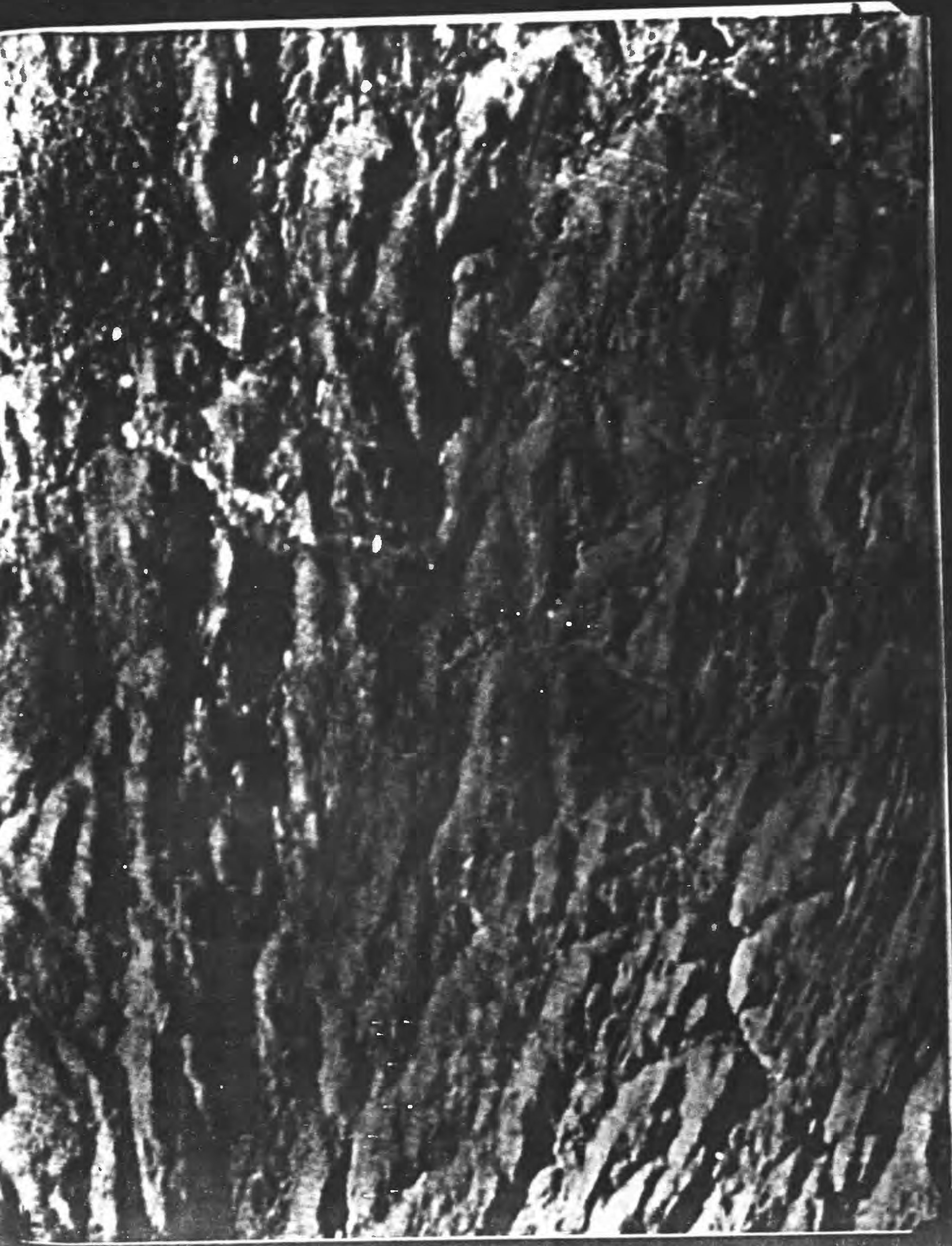


Figure 21a.- Topographic map of the area of example # 3.

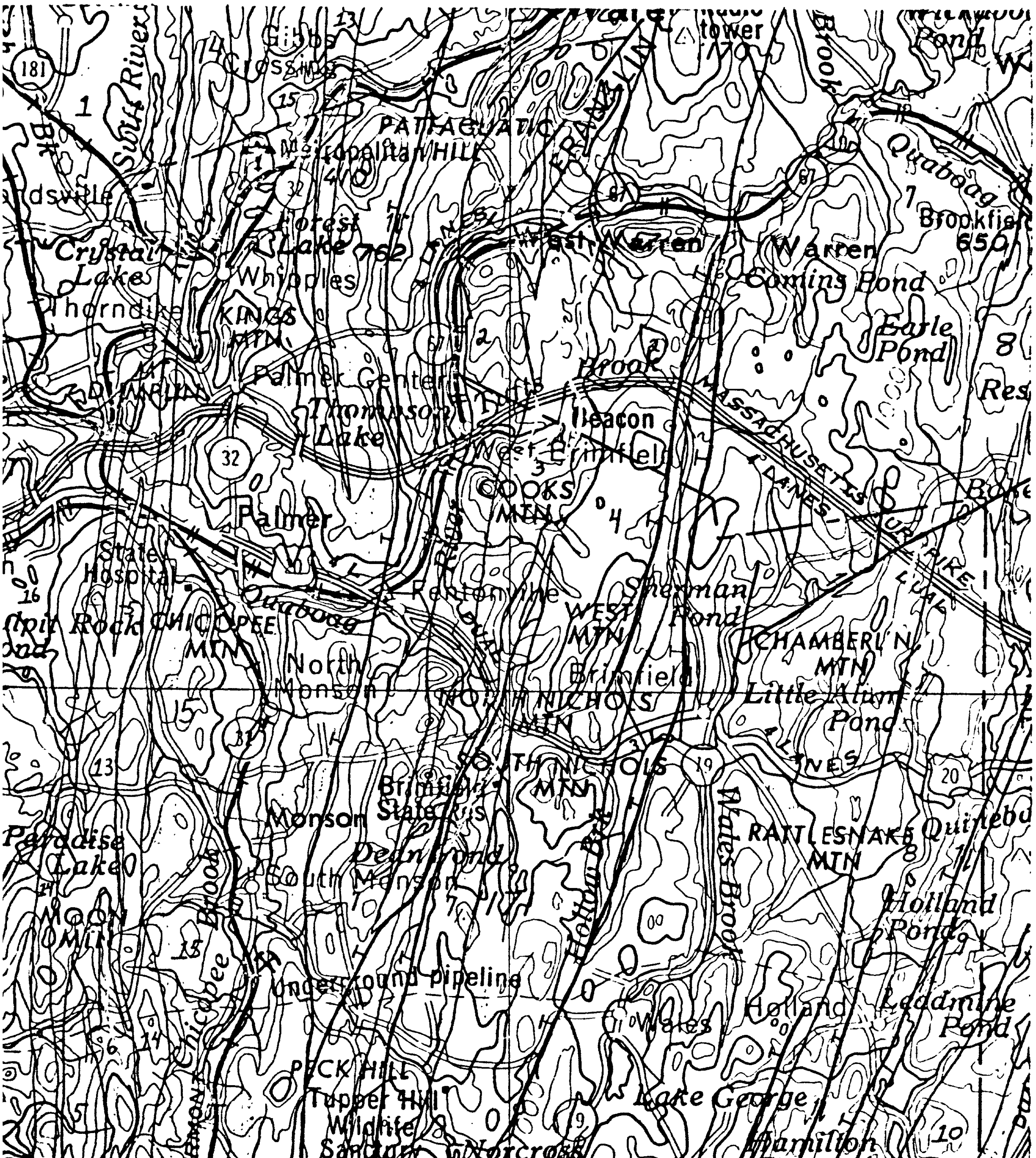

Gibbs Crossing
tower
Pond
181
Quaboag
Brookfield
650
Crystal Lake
Forest Lake
Whipples
West Warren
Warren
Comins Pond
Thorndike
KINGS MTN
Earle Pond
Palmer Center
Brook
Thompson Lake
Deacon
West Brimfield
32
COOKS MTN
Palmer
MASSACHUSETTS
State Hospital
Sherman Pond
Quaboag
CHICOPEE MTN
WEST MTN
CHAMBERLIN MTN
North Monson
Brimfield
NORTH NICHOLS MTN
Little Alum Pond
SOUTH NICHOLS MTN
Monson State
RATTLESNAKE MTN
Paradise Lake
Dean Pond
South Monson
Holland Pond
Wales Brook
MOON MTN
Chicopee Brook
Underground pipeline
Holland
Leadmine Pond
Wales
PECK HILL
Tupper Hill
Wildlife Sanctuary
Lake George
Norcross Ponds
Hamilton Reservoir
State Line
HAMPDEN CO
State Line Pond
Four Corners
Mashapaug
STATE FOREST

Figure 21a

on the imagery an area of many topographic lineaments imaged by radar parallel to those lineaments will not accurately portray the area. In the extreme northwest corner of the area a flat topography is seen on figure 21a. This area has no topographic lineaments and therefore appears similar on both of the images (figs. 19 and 20a).

Are Bedrock Geologic Features Reflected in the Topography?

The generalized bedrock geology of the Palmer (Peper, 1966), Warren (Pomeroy, 1973), Monson (Peper, 1966) and Wales (Seiders, 1973) quadrangles is shown on figure 21b. The geologic structure of the same area is shown on figure 22.

The area underlain by Devonian or younger intrusive rocks in the northwest corner of the Palmer quadrangle is visible on both figure 19 and 20a due to a tonal and textural change on the imagery. The rocks here are igneous and do not have the bedding and foliation characteristics of the surrounding rocks. The topographic expression of this lack of planar features in the intrusive rock is shown on the radar imagery by the lack of lineaments. This correspondence between radar and lithology is the best that occurs on figure 19 (the north looking imagery). The uniform texture of the remainder of the image prohibits any further lithologic interpretation. The texture of the remainder of figure 20a is not as uniform and inferences about the lithology can be made. The western half of the imagery has a different texture than the eastern half. The eastern half has a finer texture and displays many more lineaments than the western half. The correspondence of the imagery to the lithology is explained here by noting the

Figure 21 b - "Geologic" map of the Palmer, Warren, Monson and Wales Quadrangles showing lithologic contacts and faults on a topographic base at a scale of 1:125,000 and a contour interval of 100ft. in Massachusetts and 50ft. in Connecticut.

DEVONIAN ? OR YOUNGER

1 -diorite, gabbro, mafic breccia.

2 -porphyritic granite with schist inclusions.

3 -diorite, hypersthene gabbro, aplites.

PALEOZOIC ABOVE SILURIAN ? - DEVONIAN ?

4 -thinly to thickly layered,fine to coarse grained,quartz,garnet, orthoclase,plagioclase,biotite,sillimanite,cordierite gneiss and minor schist,lenses of sulfidic sillimanite schist and quartzite.

LOWER DEVONIAN

5 -graphitic,mica,garnet,staurolite schist with minor quartzite.

SILURIAN

6 -quartzite,quartz pebble conglomerate,quartz,muscovite schist.

SILURO ? - DEVONIAN ?

7 -thinly layered,fine to coarse grained,quartz,plagioclase,orthoclase, biotite,sillimanite,garnet gneiss and schist.

8 -thinly layered,fine to medium grained,quartz,plagioclase,biotite, hornblende,clinopyroxene gneiss,thinly layered,sulfidic,graphitic, sillimanite schist,thinly to thickly layered,fine to medium grained, plagioclase,hornblende,diopside,quartz gneiss and hornblende, plagioclase,biotite amphibolite.

9 -coarse grained quartz,feldspar schist and gneiss with sulfidic and graphitic schist.

10 -weakly to strongly layered,granular,plagioclase,quartz,biotite gneiss.

11 -sillimanite-rich schist and gneiss,layers of quartz-rich biotite gneiss, mafic granular gneiss, and fissile,graphitic and sulfidic schist.

12 -quartz,feldspar schist and gneiss,sillimanite schist and gneiss, granular,quartz,plagioclase,calc-silicate gneiss.

MIDDLE ORDOVICIAN

13 -sulfidic,graphitic mica schist,amphibolite and calc-silicate rock.

14 -quartz,feldspar gneiss,amphibolite,chlorite,garnet schist and gneiss.

BENEATH MIDDLE ORDOVICIAN ?

15 -layered to massive,plagioclase,quartz gneiss.

16 -coarse grained,massive to weakly foliated granitic gneiss.

-contact

-high angle fault showing relative motion

-low angle fault with T on upper plate and showing relative motion

north

0 1 2 3 4

approximate scale in kilometers

Map and explanation compiled from sources mentioned in text.

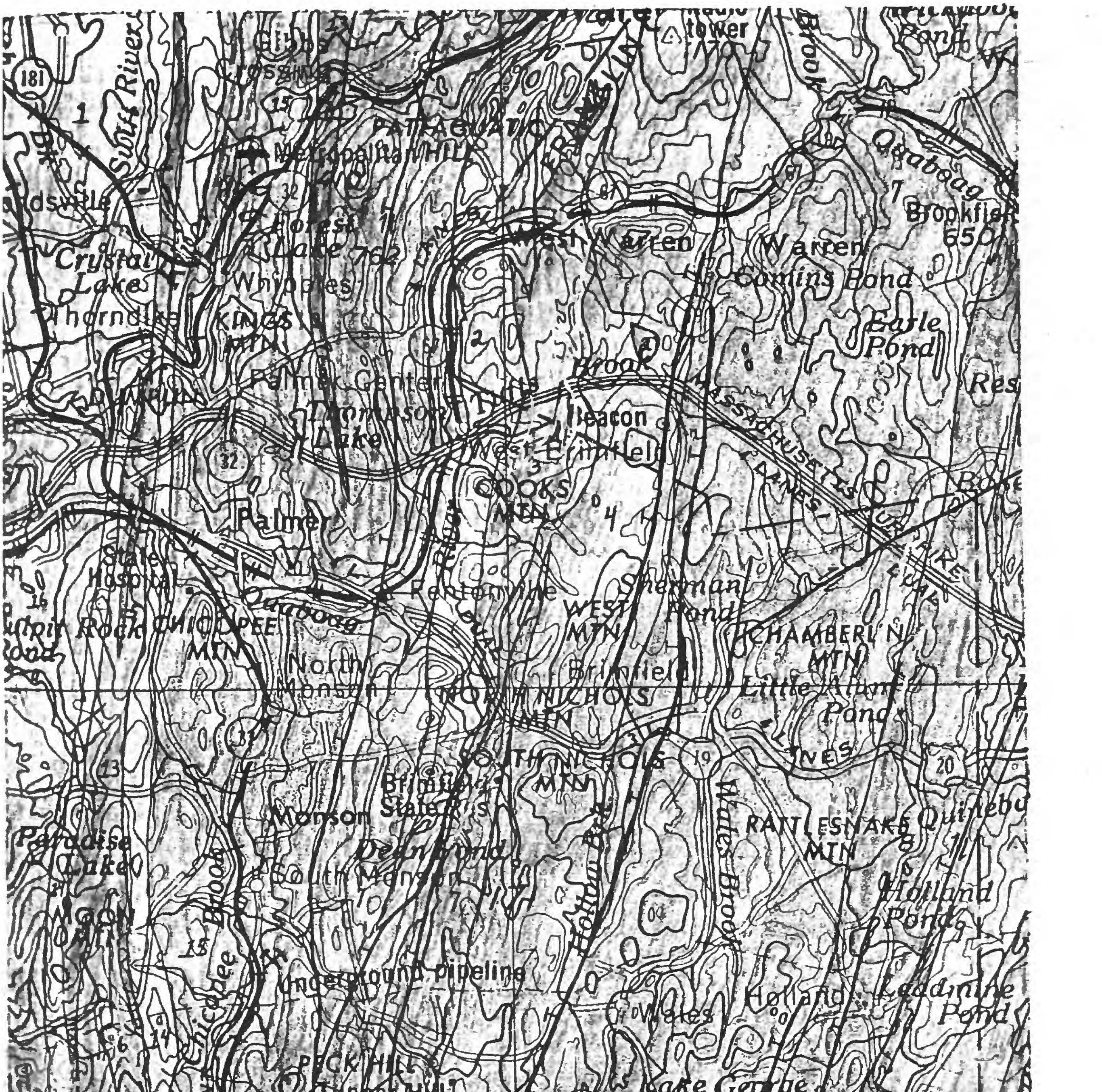

Crystal Lake
Thorndike
Forest Lake
Whipples
KINGS MTN
Palmer Center
Thompson Lake
West Warren
Warren
Comins Pond
Earle Pond
Brookfield
Quaboag
West Brimfield
COOKS MTN
Palmer
State Hospital
Sherman Pond
WEST MTN
CHICOPEE MTN
North Monson
Brimfield
CHAMBERLIN MTN
Little Alum Pond
Monson State
Dean Pond
RATTLESNAKE MTN
Holland Pond
Paradise Lake
Underground pipeline
Wales
Holland
Leadmine Pond
PECK HILL
Topper Hill
Wildlife Sanctuary
Norcross Ponds
Lake George
Hamilton Reservoir
HAMPDEN CO
Wales Brook
Hollow Brook
MASS
CONN.

Figure 21b

Figure 22 - Geologic structure of the Palmer, Warren, Monson and Wales Quadrangles on a non-topographic base at a scale of approximately 1:125,000.

contact

high angle fault showing relative motion

low angle fault with T on upper plate and showing relative motion

foliation

vertical foliation

joint

vertical joint

north

0 1 2 3 4

approximate scale in kilometers

l - low angle of dip 0-30°

m - medium angle of dip 30°-60°

h - high angle of dip 60°-90°

Map compiled from sources mentioned in text.

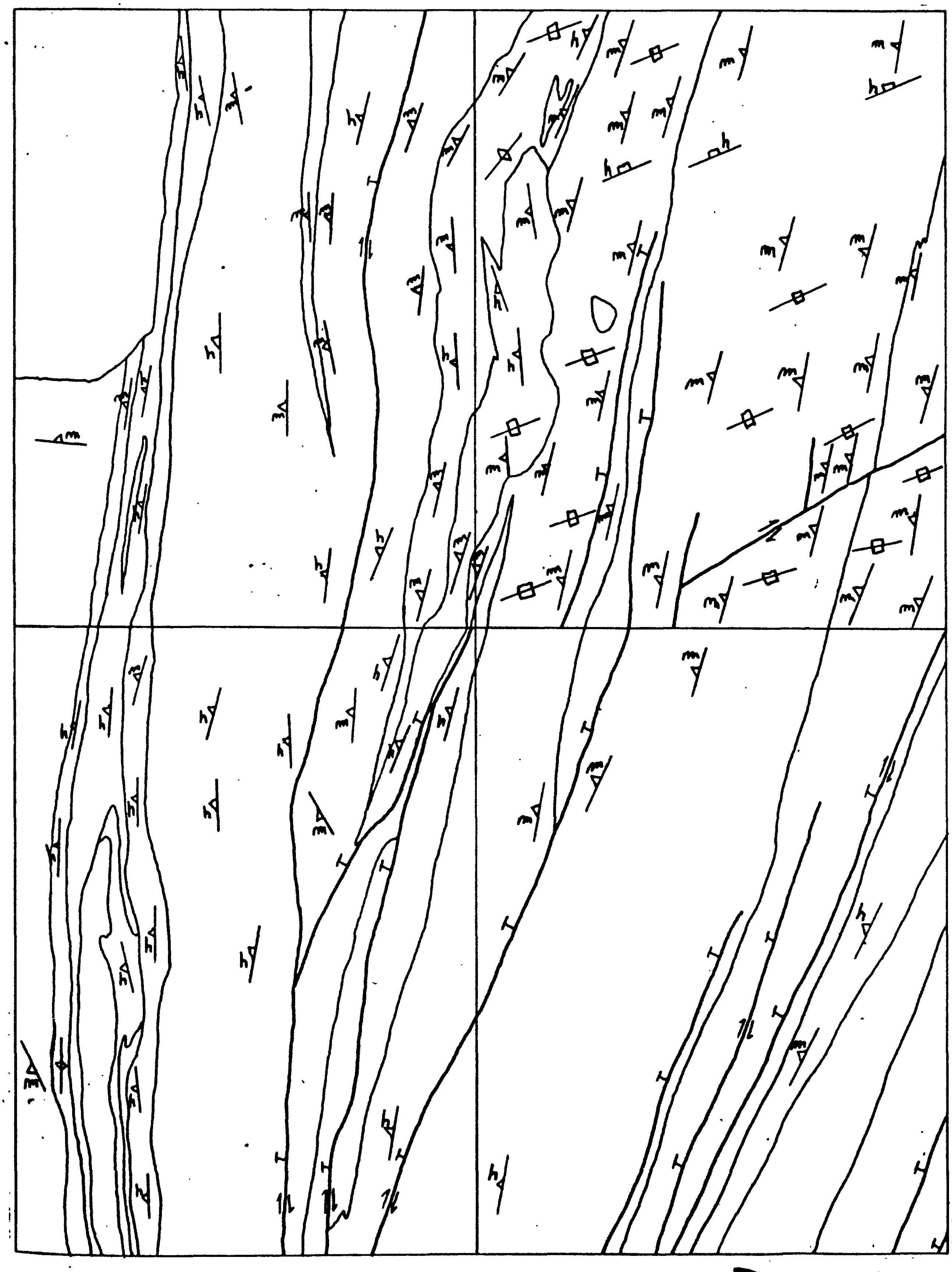


Figure 22

layering and foliation characteristics of the rocks in both areas (as seen on figure 21b, the legend for the geologic map of area # 3). The rocks underlying the western part of the imagery are more massive, largely gneisses, granitic gneisses and amphibolites compared to the mica schists and other largely schistose rocks underlying the eastern part of the area.

The structure of the area of example # 3 is shown on figure 22. A comparison of the structure with the north looking imagery (fig. 19) shows the following correspondences;

1) The northeast trending strike slip fault in the southeastern part of the Warren quadrangle is expressed on the imagery as a lineament.

2) The thrust fault cutting across the northwest corner of the Monson quadrangle is expressed on the imagery as a lineament, and.

3) Several lineaments seen on the imagery in the eastern half of the Warren and Wales quadrangles are parallel to and coincident with field mapped foliation attitudes.

Except for these correspondences, the north looking imagery reflects little of the structure of the area. As with lithology, the reason the structure is not shown better on this image is the parallelism of the look direction with the regional structural trends.

Figure 20a (the east looking imagery of the same area), on the other hand, shows remarkable correspondence with the structure of the area. All of the mapped faults in the area (fig. 22) have either partial or complete expression on the east looking imagery. They are shown as lineaments and are especially prominent in the southeastern portion of the imagery. Field mapped joints in the Warren quadrangle have minor topographic expression. The strike of foliation attitudes is particularly well expressed on the radar in the eastern extent of the area. The exceptional correspondence between geologic structure and the east looking imagery is due to a combination of two facts. First, most of the rocks of this area are well layered, moderate to steeply dipping and are cut by faults nearly parallel to the foliation and bedding and second, the look direction of the radar is nearly orthogonal to these trends.

<u>What Geologic Interpretations can be Made From Radar Imagery?</u>

Figure 20b is an interpretive radar-geologic map of area # 3 made to overlay figure 20a. The lithologic contacts have not been reinterpreted but have been directly transposed onto the overlay so as to fit the imagery. If a contact is expressed on the imagery as either a lineament or a boundary between areas of different tone and texture a solid line was used. If not, a dashed line was used. The results of the lithologic interpretation are as follows;

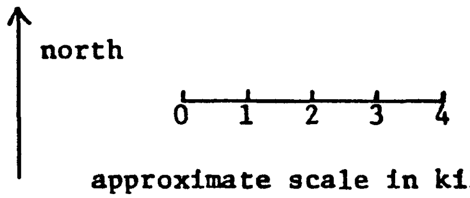
1) The intrusive rock in the northwest corner of the Palmer quadrangle is expressed on the imagery by a different tone and texture than the surrounding rocks and is therefore separable from them on the imagery. The difference is probably due to the lack of layering in the intrusive rock.

2) Segments of other lithologic contacts are expressed as lineaments.

3) The general texture of the western half of the imagery is different from that of the eastern half, indicating broadly different rock types. Specific location of contacts between the two areas, however, is difficult because the change in texture on the imagery is gradational (fig. 20a).

Figure 23 shows the radar lineaments obtained from the north looking imagery and figure 24 shows the radar lineaments obtained from the east looking imagery of area # 3. The lineaments of

Figure 23 - Radar lineament map of the Palmer, Warren, Monson and Wales Quadrangles made from the enlarged north looking imagery, scale approximately 1:120,384.



approximate scale in kilometers

+ indicates corner of quadrangle and corresponds to + on the photograph.

Lines connecting + approximate quadrangle boundaries.

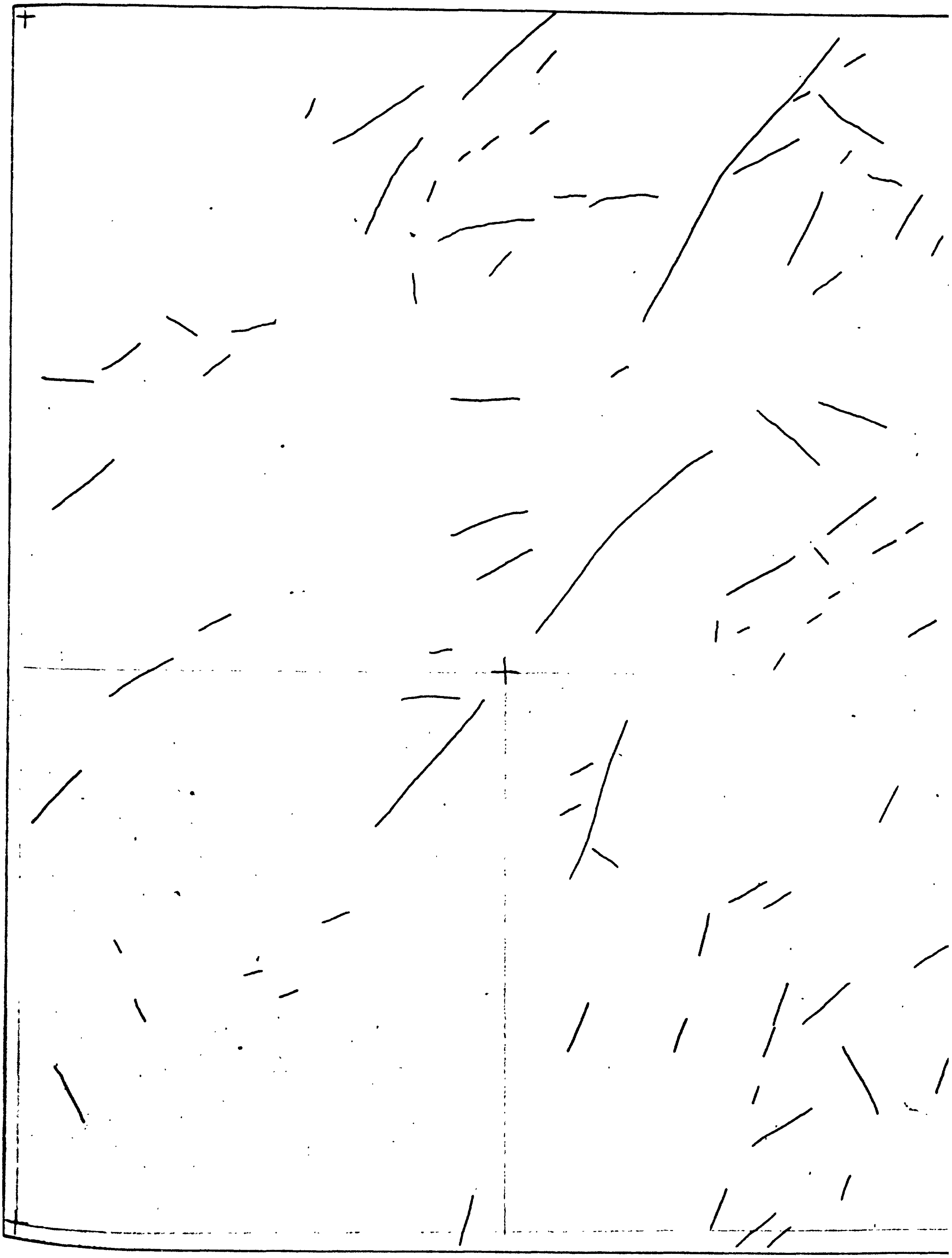
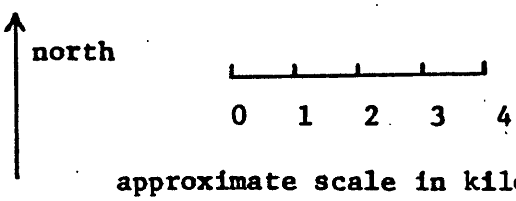


Figura 23

Figure 24 - Radar lineament map of the Palmer, Warren, Monson and Wales Quadrangles made from the enlarged east looking imagery, scale approximately 1:125,000.



approximate scale in kilometers

+ indicates corner of quadrangle and corresponds to + on the photograph.

Lines connecting + approximate quadrangle boundaries.

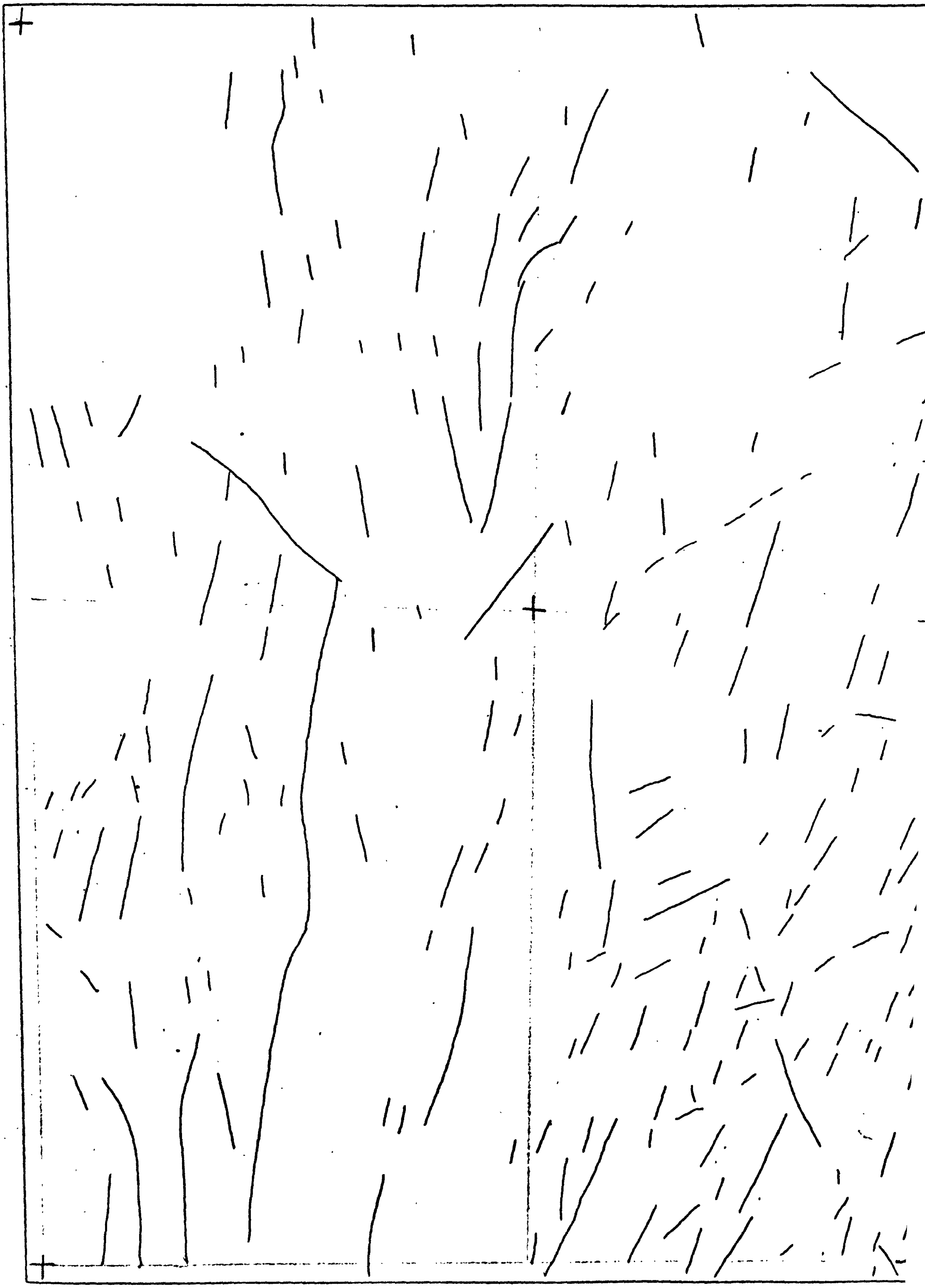


figure 24

figure 24 are interpreted on figure 20b.

Lineaments were interpreted as the strike of bedding and/or foliation attitudes for reasons given in both examples # 1 and # 2. The other lineaments on the imagery were interpreted as fractures. In the Warren and Wales quadrangles fractures could be further broken down into minor faults and joints. Most often the distinction between faults and minor faults and joints cannot be made but because of an abundance of field mapped joints in the Warren quadrangle which are parallel or subparallel to the lineaments of the area they could be interpreted as joints.

Lineaments were interpreted as fractures because;

1) They are longer and straighter than other lineaments present.

2) They crosscut the regional bedding and foliation attitudes and in places truncate ridges.

3) The northwest trending, crosscutting lineaments in the western part of area # 3, interpreted as fractures, occur in two sets with parallel members in each. These conditions are often found associated with fracturing.

<u>Summary of Findings From Examples # 1, 2, and 3</u>

1) Despite the distortions inherent to radar imagery, it presents a useful picture of the topography.

2) Orthogonal look direction coverage provides a more useful image to the geologic interpreter than opposing look direction coverage of the same area.

3) Bedrock geologic features are reflected in and have a control over the topography in the following order of importance;

   a) fractures
   b) bedding and foliation
   c) lithology

4) Radar imagery does not provide much information about the glacial geology of these areas except to support the contention that moving ice did not greatly change the bedrock topographic character (Schafer and Hartshorn, 1965).

5) The distinction between faults and joints is based on relative displacement. Since relative displacement is difficult to determine on radar the separation of faults and joints is also difficult.

6) Lineaments are interpreted as the strike of bedding and foliation if they;
   a) are parallel to field mapped bedding and foliation attitudes.
   b) are shorter and more numerous than other lineaments present.
   c) are consistent in trend over large areas and do not crosscut other lineaments.

   d) have a less distinct tonal contrast associated with them than other lineaments present.

7) Lineaments are interpreted as fractures if they;

   a) crosscut other lineaments (or the regional foliation).
   b) are longer and straighter than other lineaments.
   c) truncate or offset other lineaments.
   d) are in orthogonal sets with several parallel or subparallel lineaments in each set.

8) Lineaments can be interpreted as joints, as opposed to faults, if they;

   a) are parallel to and coincident with field mapped joints.
   b) crosscut the trends of other lineaments present.
   c) are shorter and have more of a crisscross nature than other fracture lineaments present.
   d) show no obvious relative displacement.

GEOLOGIC INTERPRETATION OF THE RADAR MOSAICS OF SOUTHERN NEW ENGLAND

Introduction

Plate 1 shows the lithology and major faults of southern New England drafted onto the shaded relief map of Massachusetts, Connecticut and Rhode Island at a scale of 1:500,000. This map was chosen because it resembles the radar mosaics and it is at approximately the same scale. The explanation for this map appears in the appendix.

Ages, local names and structural symbols were left off this map for simplicity (structural symbols appear on Plate 6). The purpose of presenting Plate 1 is to show the lithologic distribution and to allow the reader to see the contacts which were transfered onto the mosaics via overlay in their original, field mapped, geographic locations (every effort was made to keep these lines as accurate as possible with respect to geographic and topographic entities shown on the base map). The sources of information for this map are given in the appendix.

Plate 2 is the west looking radar mosaic of Massachusetts and Plate 3 is the south looking radar mosaic of Connecticut and Rhode Island. Each of these mosaics has an accompanying opposing look direction (not presented in this report). The north look direction for Connecticut and Rhode Island overlaps considerably into Massachusetts so some of the study area has opposing and orthogonal look directions.

The unenhanced, individual strips were available to the author to aid in the interpretation. It should be stressed that mosaics are not the best way to start a study of radar imagery. The individual strips that make up the mosaics afford the clearest picture to the interpreter because when several strips are placed side by side to make a mosaic the tonal contrast between strips is reduced and this decreases the resolution.

Radar Lineament Map of Southern New England

Plate 4 is a radar lineament map of the Massachusetts west looking imagery and of the Connecticut and Rhode Island south looking imagery. The lineament map was made by placing a transparent overlay onto the mosaics, backlighting it and then tracing all the linear and curvilinear tone changes onto the transparency. Lines on Plate 4 represent (a) valleys, (b) ridges, (c) cultural features such as roads, and (d) radar produced lineaments not representing anything on the terrain (e.g. scan lines). These last two causes for lineaments are very minor and probably greater than 99% of the lineaments seen on Plate 4 are actual linear topographic features. How many of these linear topographic features are bedrock controlled is an important question as well as what are the controlling bedrock features.

Plate 5 is a radar lineament histogram map showing the pattern of lineaments for fourteen different areas within the study area. The fourteen areas were chosen because each area is either structurally or lithologically distinct based on an analysis of field mapped data and interpretations put forth by numerous workers in the geology of southern New England. Also, each area appears to be distinct or at least distinguishable from each other area on the lineament map. The total area was subdivided to see if there are characteristic lineament populations from area to area. If the entire area was counted on one histogram the results would be mixed and not conclusive.

Interpretation of Radar Lineaments of Southern New England

Area 1

Geology and Physiography

Area 1 (Plate 5) includes most of the western uplands physiographic province of Flint (1930). Resistant Precambrian gneisses and lower Paleozoic gneisses and schists underlie most of the area. Biotite to sillimanite grade miogeosynclinal and eugeosynclinal (transition occuring from west to east) sediments intruded by plutonic rocks, characterize this portion of western Connecticut. The structure of the western part of area 1 is a large anticlinorium with a roughly north-south trending axis. The eastern part has many folds with axes trending north-northeast and the general regional trend of the bedding and foliation is northeast.

The glacial deposits of the area are predominantly till with stratified drift occuring in patches along the eastern and southern borders. The generalized direction of ice flow, based on drumlin axes and striations, is south-southeast.

Radar Interpretation

The structure of this area is complex and varied. Yet the histogram of the lineaments is simple and well grouped. The two nearly orthogonal peaks seen on the histogram (Plate 5) of area 1 are interpreted as fracture orientations (the reasons for this interpretation have been outlined previously in examples # 1, 2, and 3). The fracture set can be seen on Plate 6 in relation to the lithologic contacts and structural attitudes of the area. The fractures, previously unmapped, are consistent in trend over the entire western part of Connecticut. These fractures could be high angle major faults, minor faults or joint sets and they cut rocks of many different ages and types.

The N40°W and N40°E fracture set crosscuts the north-south trend of the anticlines in the western part of area 1 and also crosscuts the north to northeast trend of the fold axes in the eastern part of area 1. Many lithologic contacts in western Connecticut are parallel or subparallel to one of the trends in this fracture set. This implies that some of these contacts could be fault contacts and that fracturing plays a dominant role in the geology of the region.

Area 2

Geology and Physiography

Area 2 (Plate 5) is also in the western uplands physiographic province of Connecticut. Biotite to staurolite grade lower and middle Paleozoic eugeosynclinal rocks (mostly phyllites to schists) underlie the region. The structure is marked by a northeast trending syncline which is cut by high angle faults parallel to the axial trend of the folds. The regional trend of the bedding and foliation is also northeast.

Till and stratified drift cover the area with the stratified sands and gravels thickening towards the ocean. The ice flow direction here is slightly more southerly than in area 1.

Radar Interpretation

The lineament direction peaks at N50°W and N30°E are the most prominent on the histogram (Plate 5). The N50°W lineaments are interpreted to be fracture controlled and the N30°E lineaments are controlled by a combination of fractures and bedding and foliation. Plate 6 shows that the structural attitudes parallel the field mapped faults in the region. This explains the peak at N30°E as well as the difference in magnitude between the N30°E peak and the N50°W peak (i.e. the attitudes and the fractures trend in the same direction).

Several new fractures have been interpreted in this area which are parallel to the field mapped faults and in the same vicinity. These can be seen on Plate 6.

Area 3

Geology and Physiography

Area 3 (Plate 5) is the southern half of the Connecticut Valley lowlands physiographic province of Flint (1930) and Emerson (1917). This broad, flat region is underlain by relatively nonresistant, shallow dipping sandstones and shales with some resistant basalts rising above the sedimentary terrain. The rocks of this area are Triassic in age and are structurally in a half graben downthrown on the eastern side. Bedding in the sedimentary rocks trends north to slightly northeast.

Thick Pleistocene sands and gravels abound in this area but towards the northwest till becomes more common. Drumlins are numerous in the Connecticut Valley lowlands and generally trend north-south.

Radar Interpretation

The number of lineament counts for this area is small because the bedding is shallow dipping and the various interbedded sedimentary units here have similar resistance to erosion. The histogram of area 3 (Plate 5) almost duplicates that of area 2 and does so because the same fracture pattern cuts both areas. Lineaments in the Triassic valley are due to the resistant basalt ridges whose contacts with the sedimentary rocks are nearly parallel to the fracture pattern of the area. Thus the same fracture pattern that cuts the very much older crystalline rocks to the west also cuts the Triassic rocks. And, since these fractures have a topographic expression and because of supporting field mapped data, it can be assumed that the fractures are steeply dipping to vertical. The fracture set of this region is shown on Plate 6.

Area 4

Geology and Physiography

Area 4 (Plate 5) lies completely within the eastern uplands physiographic province of Connecticut (Flint, 1930). Metamorphic grade in the area ranges from the staurolite to the sillimanite-orthoclase zone of regional metamorphism. The Paleozoic gneisses and schists which underlie this area were originally eugeosynclinal sedimentary and volcanic rocks and have subsequently been intruded by igneous rocks of various ages. The structure of this region is complex. In its extreme western part a north-south trending anticlinorium, marked by gneiss domes and tight isoclinal folds, stands in sharp contrast to the Triassic rocks immediately to the west. East of the anticlinorium a north to northeast trending synclinorium makes up the largest part of the area. Near the southern end of this synclinorium an east-west trending thrust fault truncates the structural trend of the synclinorium and south of the fault gneiss domes and recumbent anticlines and synclines, intruded by numerous granite bodies, characterize the area. The predominant trend of the bedding and foliation in the synclinorium is northeast. The eastern extent of area 4 (near the Rhode Island border) is underlain by a broad anticlinorium made up of Paleozoic plutonic rocks. A series of north-south trending thrust faults separates the synclinorium from the igneous rocks.

Most of area 4 is covered by till with stratified deposits occuring in a north-south trending belt approximately coinciding with the boundary between the plutonic rocks near the Rhode Island border and the eugeosynclinal metasediments and metavolcanics. Stratified sands and gravels also are found along the shoreline. Ice flow direction in the area is generally north-south swinging slightly southeast near the shore.

Radar Interpretation

The histogram for this area (Plate 5) shows two distinct peaks, one at N40°W and one at N30°E, and another less distinct peak trending east-west. The east-west trending group of lineaments is related to the large, field mapped thrust fault in the southern part of the area as seen on Plate 6. The N40°W group is interpreted to reflect fractures and the N30°E group is larger because it reflects not only fracturing but foliation and bedding attitudes also. The fracturing is again nearly orthogonal and also nearly parallel to the orthogonal fracture sets in other areas.

Plate 6 shows the interpreted fractures of area 4. Along the eastern border of the area several new fractures have been interpreted that are parallel to and in the same vicinity as field mapped faults. South of the roughly east-west trending fault in the southern part of area 4 (as seen on Plate 6) many fractures, trending northwest-southeast, have been interpreted. This particular pattern can also be seen north of the thrust fault and seems to pervade all of eastern Connecticut.

Area 5

Geology and Physiography

Area 5 (Plate 5) is also entirely within the eastern uplands physiographic province of Connecticut. The rocks of the area are sillimanite-orthoclase grade, Paleozoic metasediments and metavolcanics. Structurally these rocks are in the same synclinorium that underlies much of area 4. Attitudes here are steeply dipping and trend north-northeast. Numerous faults, subparallel to the regional bedding and foliation trend, are present (Plate 6). The rocks of area 5 were separated from area 4 because they have good topographic expression and because the lineament trend is consistent and appears to be shifted towards the north.

The glacial drift of this area is almost all till and the drumlins trend south-southeast.

Radar Interpretation

The predominant structural trend in this area is northeast, as seen on Plate 6. The N20°E peak reflects the bending of the bedding and foliation attitudes. The magnitude of this peak is due to that plus the fact that faults in this area are subparallel to the bedding and foliation. The N40°W group is a fracture trend which clearly crosscuts the trend of the bedding and the trend of the other fractures.

Plate 6 shows these newly interpreted fractures of area 5 and their relationship to the field mapped geologic data. Most of the new fractures trend northwest and are parallel to some previously mapped faults of the area. In the western part of area

5 some northeast trending fractures are interpreted.

Area 6

Geology and Physiography

Area 6 (Plate 5) is the northern part of the Connecticut Valley lowlands physiographic province of Massachusetts and Connecticut. Triassic conglomerates, arkoses and shales underlie this flat region except where basalts of the same age create resistant ridges. The structure of the area is homoclinal with the bedding trending north-south and dipping slightly to the east. The sedimentary and volcanic rocks occupy a graben-like basin downthrown on the eastern side.

Thick glacial lake sediments overlie most of the basin and the numerous drumlins here trend north-south.

Radar Interpretation

The north to N30°E trend of the bedding in this area (Plate 6) is clearly reflected in the histogram (Plate 5). The N40°E grouping is interpreted as fracturing and it coincides with fracture patterns seen both to the east and west of the Triassic basin.

Area 7

Geology and Physiography

Area 7 (Plate 5) covers both the Taconic and Berkshire Highlands physiographic provinces of Emerson (1917) in western Massachusetts. The western one-third of the area is underlain by a lower Paleozoic miogeosynclinal sequence of limestones and sandstones metamorphosed to the garnet zone of regional metamorphism. Rising above these relatively nonresistant rocks are the phyllites and schists of the allochthonous

Taconic sequence, which lies unconformably on the miogeosynclinal rocks. East of this are the Precambrian resistant gneisses and lower Paleozoic eugeosynclinal rocks that make up the Berkshire Highlands.

East of the Precambrian highlands is an approximately north-south trending synclinorium of Paleozoic eugeosynclinal rocks. Interupting the synclinorial sequence are bodies of plutonic rocks and a series of gneiss domes trending approximately parallel to the axis of the synclinorium. The predominant structural trend in this area is north to slightly northeast.

Glacial till overlies nearly the entire region. And, although drumlins are scarce in this area, the general direction of ice flow is southeast.

Radar Interpretation

The trend of the bedding and foliation attitudes in the synclinorium in the eastern part of area 7 (Plate 5) is reflected on the histogram as a north-south peak. The magnitude of this grouping is also partly due to the north-south trend of the Precambrian anticlinorium. The N40°W to N20°W grouping represents a prominent fracture set which clearly crosscuts the regional structural trends. A less distinct peak at N10°E to N40°E reflects a fracture set nearly orthogonal to the first.

The fractures of this area can be seen on Plate 6. A marked northwest trend is seen for these newly interpreted fractures. It is also interesting to note that fracture patterns cutting one group of rocks cut most of the rocks in the area in the same way.

A north-south trending, high angle fracture can be seen in the northwest corner of area 7.

Area 8

Geology and Physiography

Area 8 (Plate 5) is in the extreme western part of the Worcester County plateau physiographic province of Emerson (1917). The rocks here are staurolite to sillimanite grade, lower Paleozoic eugeosynclinal rocks intruded by large bodies of igneous rocks. The structure of the area includes many gneiss domes (the gneiss domes may be of igneous or sedimentary origin and are granitic in composition) lined up along the north-south axis of a regional anticlinorium. The regional trend of the bedding and foliation is north-south.

Till covers most of the area and the ice flow direction is south.

Radar Interpretation

The north-south trend of the rocks in the regional anticlinorium of area 8 can be seen in the histogram on Plate 5. Two other peaks, at N30°W and N50°E, are interpreted as fracture patterns. Both these fracture directions crosscut the regional trend of the bedrock. This crosscutting relationship can be seen on Plate 6 where the lineaments of the area are interpreted and shown with the field mapped lithology and field mapped structural attitudes. Several new lineaments, interpreted as fractures and trending northeast, are prominent in the northern part of area 8.

Area 9

Geology and Physiography

Area 9 (Plate 5) is completely within the Worcester County plateau physiographic province in Massachusetts.Lower Paleozoic, sillimanite grade, eugeosynclinal rocks, intruded by younger plutonic rocks, underlie the area.

The sillimanite grade rocks occur in a north-south trending anticlinorium. Along the axis of the anticlinorium a number of gneiss domes, separated by synclines of the Paleozoic eugeosynclinal rocks, occur. The general structural trend here is north-south.

The glacial geology of area 9 is very similar to that of area 8.

Radar Interpretation

The trends of the metamorphic rocks in area 9 (Plate 5) are seen in the histogram. The overwhelming percentage of lineaments here reflect the attitudes of bedding and foliation. The N20°W peak probably represents a fracture trend. A small grouping also occurs at N30°E and is also a fracture trend. In this area the trends of the bedding and foliation are predominant on the histogram. This is due partly to the strongly schistose, steeply dipping and consistently north-striking character of the rocks in the area.

A strongly developed, northeast trending fracture pattern can be seen on Plate 6 in the northern part of area 9. These fractures cut across the trend of the anticlinorium and continue on into area 11.

Area 10

Geology and Physiography

Area 10 (Plate 5) is in the south-central part of the Worcester County plateau physiographic province in Massachusetts. The rocks are sillimanite grade, lower Paleozoic gneisses and schists. The region is part of a broad north to northeast trending synclinorium characterized by steeply dipping beds with low angle faults cutting the rocks subparallel to the bedding. The surficial geology is dominated by till and the drumlins in the area trend south to slightly southeast.

Radar Interpretation

The histogram of area 10 (Plate 5) is similar to that of area 5 except that the trend of the bedrock is more northerly here. The largest grouping in the histogram is the north-south to N20°E grouping which reflects the trends of bedding, foliation and low angle faults. Peaks at N20°W and N50°E represent an orthogonal fracture set present over much of southern New England.

Area 10 has a strongly developed north to slightly north-east trend of the bedding and low angle faults (as seen on Plate 6). The interpreted northeast trending fracture set of the area clearly crosscuts the regional trend of the foliation.

Area 11

Geology and Physiography

Area 11 (Plate 5) is the easternmost part of the Worcester County plateau in central Massachusetts. The area is the northern continuation of the north to northeast trending synclinorium of area 10. The rocks here are lower Paleozoic, biotite to sillimanite grade gneisses and schists intruded by large igneous bodies in numerous places. The synclinorium swings more northeasterly towards the northern border of Massachusetts. At its eastern border there is a series of northeast trending, northwest dipping thrust faults which sharply separate the different geology to the west from that of the east.

The western part of area 11 is covered by till and characterized by the south to southeast ice flow direction found over most of the Worcester County plateau. In the northeast part of area 11 the drift is stratified and thickens considerably. The easternmost part of the Worcester County plateau is the beginning of an area of eastward thickening glacial drift and generally low bedrock relief.

Radar Interpretation

The pronounced north-south peak on the histogram of area 11 (Plate 5) reflects the predominant trend of the synclinorium underlying the area. The decreasing, but still visible, grouping ranging from north-south to N30°E reflects the northeast bending of the structural belt as it nears the northern border of Massachusetts. Newly interpreted fractures in this area have peak trends at N40°-50°E and at N20°W. Plate 6 shows these patterns. The northeast trend of the fractures can be seen in the central part of the area. They are in contrast to the northerly trend of the regional structure.

In the extreme eastern portions of area 11 the bedrock relief is beginning to lessen and the glacial drift thickens. Here some drumlins have been interpreted and can be seen on Plate 6.

Area 12

Geology and Physiography

Area 12 (Plate 5) is the northern most section of the seaboard lowlands physiographic province of Emerson (1917). The rocks are chlorite to sillimanite grade gneisses and schists of lower Paleozoic age. Precambrian and Paleozoic plutonic rocks are also present.

The area is bounded on the northwest by a series of northeast trending thrust faults and on the southeast by similar faults of approximately the same trend. The predominant structural trend here is northeast.

The area is covered by thick glacial drift, most of it being stratified. The drumlins trend southeast in the northern part and swing more to the east further south.

Radar Interpretation

Area 12 is covered with thick glacial drift and this lessens the topographic expression of bedrock geologic features. The large grouping on the histogram between N20°-50°E does, however, reflect the combined trends of the thrust faults and the bedding and foliation attitudes of the rock units as seen on Plate 6. A peak on the histogram occurs at N40°W. This represents a fracture pattern which is interpreted and shown at the extreme western part of the area (Plate 6). In the northern part of area 12 some lineaments have been interpreted as drumlins.

Area 13

Geology and Physiography

Area 13 (Plate 5) comprises the remainder of the seaboard lowlands physiographic province in Massachusetts and the Naragansett basin lowlands province in Rhode Island (Flint, 1930). The area is underlain by Precambrian and lower Paleozoic plutonic rocks with three large, metamorphosed, fault bounded Carboniferous sedimentary basins (the Boston, Norfolk and Naragansett basins) superimposed on the igneous terrain. The rocks in the basins are conglomerates, sandstones and shales. The igneous rocks are found in a broad anticlinorial arch underlying most of the area. The sedimentary rocks in the Carboniferous basins are folded and the general structural trend is northeast.

Till and thick stratified drift cover the area. The southeastern extent of area 13 has the thickest glacial deposits of any area mentioned thus far and is second only to Cape Cod in total thickness of glacial drift (Cape Cod has a glacial cover in excess of 100m thick). Drumlin axes swing back to the southeast from the almost east-west trend found in the extreme northeast part of the area.

Radar Interpretation

Despite the large size of area 13 the number of lineaments present is greatly reduced compared to the other areas. There are two reasons for this, first, the terrain is largely underlain by igneous rocks, and second, the glacial drift is very thick in relation to the bedrock relief. The histogram groups at N10°-20°W and at N20°-30°E are interpreted as fracture controlled. Faults seen bordering the sedimentary basins on Plate 6 coincide with these trends on the histogram. Several newly interpreted fractures, which partially control the shape of the coastline, can be seen in the southern part of area 13 on Plate 6.

Area 14

Geology and Physiography

Area 14 (Plate 5) is the western extension of the eastern uplands physiographic province in Connecticut (Flint, 1930). This uplands area is underlain mostly by Precambrian and Paleozoic granitic rocks. Some small areas of lower Paleozoic eugeosynclinal rocks as well as two small Carboniferous basins interupt the igneous terrain. The structure can be broadly classified here as anticlinorial.

Till and stratified drift are about equally plentiful over the area and both are thick. In its extreme southern portion, area 14 has one of the few terminal moraines in southern New England parallel to the shoreline.

Radar Interpretation

The general topographic character of this area is different than those areas underlain mostly by metasedimentary and metavolcanic rocks. The largely igneous terrain is uniform in texture and has markedly fewer topographic lineaments. The trends on the histogram of area 14 (Plate 5) at N40°W and N40°E represent fracture patterns which are nearly orthogonal and which are similar to other patterns cutting the entire region. Plate 6 shows the newly interpreted fractures of this area. The northern part of area 14 shows particularly well the northwest trending fractures. The terminal moraine present in area 14 is not expressed by topographic lineaments.

Cape Cod

Cape Cod is the unnumbered area seen on Plate 5. No lineament histograms were prepared for this area because bedrock is so deeply buried (greater than 150m) by stratified drift and terminal moraine that no topographic expression of bedrock features is present.

The only interpretation made for the area of Cape Cod appears on Plate 6. Here, in places, the distinction between end moraine and stratified glacial drift could be made because the end moraine has much greater topographic relief associated with it. Lineaments seen on Plate 4 for this area reflect either present drainage patterns imposed on the outwash plains or contacts between till (in the end moraines) and sand and gravel (in the outwash plains).

Interpretive Radar-Geologic Map of Southern New England

Plate 6 is made to overlay the radar imagery of southern New England and show exactly where the lithologic contacts, faults and some bedding and foliation attitudes are located. It also shows lineaments that were interpreted as fractures. The only items on this map that were interpreted by the author are fracture trends, indicated by a dot-dash line,and some few drumlins in northeast Massachusetts. Everything else was transfered directly from field mapped information onto the overlay in its proper place.

In a few places shown on Plate 6 the radar image which it overlays becomes blurred. One such area is in south-central Massachusetts, east of the Triassic basin, and another area is in Massachusetts just north of the Rhode Island border. These areas of lost or hidden terrain are drawbacks when close detail is important but are not critical if regional studies are required.

The fracture trends on this map were interpreted by methods previously outlined in examples # 1, 2, and 3.

SUMMARY AND CONCLUSIONS

Discussion of Regional Fracture Patterns

The most important fact to arise from this study of the radar imagery of southern New England is the existence of a nearly orthogonal fracture set which cuts the entire area irrespective of rock type or geologic age. L.R. Page (1969), in a preliminary study of the same radar imagery, concludes that fracturing was more important to the understanding of the geology of the area than was previously recognized. The fracture set is not exactly orthogonal, nor is it constant in all areas. It is a system of nearly vertical fractures trending N20°-50°W over all of southern New England, intersected by another system of nearly vertical fractures trending N20°-50°E over all of the same area.

The idea for this system of fractures arose from inspection of the lineaments map (Plate 4) and the lineaments histogram map (Plate 5). Support and further ideas for it came from two writers, Hobbs and Gay, who did their work seventy years apart. The first, W.H. Hobbs, studied topography and drainage patterns in Connecticut and the whole east coast of North America and concluded that;

1) The earth is broken by a series of fracture sets which are vertical, subequally spaced, and have only a few primary strike directions.

2) The primary fracture pattern of the earth is produced by two bisecting, rectangular fracture sets.

Hobbs' papers putting forth this theory (Hobbs, 1900 and 1911) were not met with great approval and the concept faded. Recent workers, however, seem to be coming up with evidences, from different data sources, leading to the same, or similar, conclusions.

Gay (1973) summarizes these recent findings concerning orthogonal fracturing as follows;

1) The crust of the earth is cut by a number of parallel to subparallel fractures that occur everywhere throughout the globe.

2) Every fracture set is paired with another set orthogonal to it.

3) The fractures must have formed originally by vertical movement. Any horizontal movement is later in origin, but much vertical movement must be later also. The fractures could have been reactivated at numerous times subsequent to their formation.

4) This fracture set has been successfullt mapped by the following techniques;
   a) Topographic analysis from topographic maps.
   b) Airphoto lineament studies (including space photos).
   c) Side looking airborn radar imagery studies.
   d) Aeromagnetic lineament studies.

5) The fracture sets first occur in the basement rocks and can subsequently be imprinted onto overlying sedimentary rocks, solidifying plutonic rocks or high grade metamorphic rocks. In this way a fracture set could be perpetuated through a cycle of regional metamorphism.

6) The age and means of formation of these basement fracture sets is unknown. However the fracture sets are probably of early Precambrian age and they resulted from vertically directed forces.

The results obtained from the present study compare favorably with many of Gay's points. Southern New England is characterized by a number of parallel to subparallel fractures. And for each parallel group of fractures there is another group of parallel fractures orthogonal to it. This pattern persists over the entire study area.

The theory that the fractures were formed originally by vertical movement (Gay, 1973) is supported by the good topographic expression that this fracture pattern has. Vertical, planar features, be they faults, joints or bedding planes, are reflected in the topography better than non-vertical or horizontal features. The fracture set mapped in this report is either vertical or close to vertical. Of course a vertical fracture does not have to be formed by vertical movement so any interpretation as to the mode of origin of these fractures, based on findings from this study, is not possible.

Another interpretation of Gay (1973), that vertical fracturs started in the basement rocks and could be imprinted on any overlying rocks by subsequent reactivation of the old fracture, is hard to prove from the results of this analysis. The fracture pattern mapped in southern New England cuts folded, metamorphosed rocks, as well as plutonic and sedimentary rocks. If all the types and ages are cut in a similar fashion then it is probable that the fracture causing conditions occured after the regional metamorphism and after the deposition of the youngest rocks present. The possibility exists that such conditions did, however, reactivate old basement fractures, but it can not be proven here. The only safe assumption as to the age of formation of the newly mapped fracture set is that it occured later than the youngest rocks affected, namely the Triassic rocks of central Massachusetts and Connecticut.

Newly Interpreted Fractures and Fracture Groups

Fracture lineament AA', seen in western Massachusetts (Plate 6), is characteristic of the newly interpreted fracture lineaments of that area. AA' is here interpreted as a fault which cuts the rocks in the vicinity of Russell, Huntington, Chester and Hinsdale Massachusetts at a high angle and which trends approximately N30°W. Many fracture lineaments parallel to AA' cut the Precambrian and Paleozoic rocks of the region. The lineaments extend for kilometers and maintain a very consistent trend throughout the area. This trend cuts the regional bedding and foliation trends in many places as shown on Plate 6. Also, a body of metamorphic rocks projects westward into the Triassic sedimentary valley from the east side of the valley and northeast of the southern end of AA'. The contact of the older metamorphic rocks with the younger sedimentary rocks parallels the fracture trend west of the valley and lends support to the interpretation of the lineaments of this region as being fault controlled.

Further east in Massachusetts (Plate 6) fracture lineament BB' can be seen extending approximately 60 kilometers, with a strike of N40°E, from the town of Ware northeast through South Barre and into Fitchburg. BB' coincides with several irregularities in the lithologic contacts in the area and also has a very good topographic expression in its western extent (see Plate 2). Many lineaments in this central portion of Massachusetts are parallel to BB' and have also been interpreted as fracture lineaments. The regional structural trend in this area is generally north-south, swinging more to the northeast in the eastern part of central Massachusetts. This N40°E fracture pattern, therefore, crosscuts this trend. Emerson (1917) made reference to the possibility of a "great fault" existing in the area south of Ware, Massachusetts (this is at the extreme western extent of the lineament BB'). The SLAR data corroborates the presence of a large fault in central Massachusetts.

Fracture lineament CC' in western Connecticut (Plate 6) trends N40°E through the towns of New Milford (at the southern end), New Preston, Bantam and Torrington. CC' parallels many other fracture lineaments in the area. The fracture trend of N40°E cuts nearly all of the rocks of the area. Another well developed fracture set, almost orthogonal to the N40°E set, cuts the area. As with fault BB' many lithologic contacts are offset along the trend of this lineament. The fact that contacts are offset or truncated along CC' and other parallel lineaments supports the interpretation of those lineaments as faults. At the western end of CC' a north-trending body of sedimentary rock is cut off along the fault CC'.

In eastern Connecticut two fracture lineaments are labelled, DD' and EE' (Plate 6). DD' is located in central Connecticut near the towns of Chestnut Hill, Willimantic, North Windham and Chaplin and trends approximately N40°E. DD' is a segment of a longer lineament pattern that begins at the southern end of the large body of sedimentary rock in central Connecticut (the Triassic basin). The field mapped eastern border fault of this basin, at the southern end of the basin, begins the lineament which continues at N40°E up through east-central Connecticut. Other lineaments in eastern Connecticut parallel DD' and are also interpreted as fracture controlled. EE' is a newly interpreted fracture lineament that cuts the rocks of southeastern Connecticut in the towns of Oakdale, Montville, Uncasville and Gales Ferry almost orthogonally to DD'. This pattern (N40°W) clearly crosscuts the local bedding and foliation attitudes at the northern extent of the fracture lineament but parallels the foliation further south. The area of EE' is one of complex lithology and structure and the relationship of this new fracture lineament to the geology of the area is unclear. The fracture trend does coincide with the arratic change of direction of some of the lithologic contacts in the area. Both DD' and EE' are here interpreted as major high angle faults cutting the rocks of eastern Connecticut in a near orthogonal pattern.

In Rhode Island two newly interpreted, nearly orthogonal fracture lineaments are seen on Plate 6, FF' and GG'. Lineament FF' cuts the rocks of northern Rhode Island from Cranston northwest through North Scituate and almost over to the Rhode Island-Connecticut border. Lineament GG' trends northeast from near Coventry, through the northwest part of Providence and ends near Pawtucket. These lineaments are typical of the fracture lineaments in Rhode Island. The lineaments are cutting a predominantly igneous terrain and also can be seen to clearly intersect each other. It is not possible, as with other intersecting lineaments seen on Plate 6, to determine which lineaments were formed earliest as no relative displacement of either lineament can be seen. FF' and GG' are interpreted to be faults, cutting each other as well as the rocks of northern Rhode Island.

It is hoped by the author that the newly interpreted fracture lineaments on Plate 6, some of which are faults with great displacement, some are faults with minor displacement and some are joint groups or swarms, will serve to aid in the understanding of the local geology and help focus attention to anomalous geologic areas in the field.

Findings About Radar Imagery

The following list is a summary of the important findings of this study related to the use of radar imagery in geologic interpretation;

1) A radar imagery mosiac has many distortions in it which affect both the quality of the imagery and the scale of the imagery. Some of the distortions can be optically or computer corrected but in most cases these proceedures reduce the usefulness of the image somewhat.

2) An individual radar strip is better suited for detailed studies of small areas but for regional scale studies the mosaic provides more information.

3) The distortions present in radar imagery do not severely hamper regional studies. They could, however, render the study of larger scale areas (e.g. 1:24,000) impossible. The best working scale for the radar imagery used in the present study is between 1:100,000 and 1:500,000.

4) The radar imagery of southern New England approximates a shaded relief map of the same area.

5) Linear topographic features are expressed very well on radar imagery except when the strike of topographic lineaments is parallel or near parallel to the look direction. In this case the feature may be completely subdued or lost on the imagery.

6) Opposing look direction coverage does not greatly increase the amount of information obtainable from the radar imagery because if a topographic feature is parallel or oblique to one of the opposing look directions it will have the same relationship to the other look direction.

7) Orthogonal look direction coverage does increase the amount of information obtainable from the radar imagery.

8) One look direction imagery supplies greater than 75% of the maximum obtainable information in an area where the structural trends are consistent and the information obtainable from each additional look direction decreases.

9) Radar imagery shows the topography and enhances topographic lineaments. It can only be used to interpret those bedrock geologic features that have a topographic expression.

10) The bedrock geologic features in the study area that have topographic expression are;
   a) fractures
   b) bedding and foliation
   c) lithology
   and in that order of importance.

11) The best application of radar imagery is for regional lineament studies, most of the lineaments seen on the imagery are expressions of fractures (i.e. faults, minor faults and joints).

12) Fracture lineaments are identified by any or all of the following criteria;

   a) They are long, straight and persistent lineaments.
   b) They crosscut the regional trend of the bedding and foliation.
   c) They offset or truncate ridges and valleys.
   d) They are almost always accompanied by other lineaments parallel to each other.
   e) In this study area they are also almost always accompanied by another set of lineaments striking anywhere from 70-90 degrees from the first.

13) Bedding and foliation lineaments are recognized by the following characteristics;
   a) They are shorter and not as straight as fracture lineaments.
   b) They do not persist over large areas and they are commonly less distinct than fracture lineaments.
   c) Bedding and foliation attitudes are commonly recognized by swarms of these short, indistinct lineaments. Individual lineaments are not diagnostic but over several square kilometers a repeating pattern of this type of lineament helps in the recognition of them as structural attitudes.

14) Drumlins and end moraines are the main glacial features having topographic expression visible on the radar imagery. Drumlins are too small for the scale of the radar in this report to be prominent in any area except where the surrounding relief is very small.

15) The distinction between different types of glacial deposits is not possible except on Cape Cod where there is no bedrock topography and end moraines have sharp relief in contrast to the very low relief of outwash deposits.

16) In most places the direction of ice flow is not ascertainable on radar imagery at the scale of this study (i.e. 1:500,000).

Comparison of Radar Imagery with Conventional Aerial Photography

1) The scale accuracy of most air photos is better than the scale accuracy of radar imagery.

2) Air photos can be viewed in stereo which greatly increases their interpretability. Radar can be viewed in pseudo stereo at best.

3) Since conventional air photos are taken at a larger scale than radar imagery more detail of a given area can be studied.

4) Radar is not dependent on weather conditions or time of day as are air photos.

5) Radar shows synoptic views of large areas in a way which enhances topographic relief, and therefore is better suited to regional studies than are conventional air photos.

6) More accurate measurements, both vertical and horizontal, can be made with air photos than with radar imagery.

7) The shadow enhancement of the topography enjoyed on radar imagery can be varied depending on which direction you want to view the terrain from, conventional air photos are restricted to a mostly unshadowed, near vertical image.

8) A mosaic of an area using radar image strips requires much fewer individual pieces than a mosaic of the same area using conventional air photos.

Comparison of Radar Imagery with Low Sun Angle Photography (LSAP)

1) Low sun angle photography tries to copy the affect of radar imagery by taking the photograph when the sun is in such a position as to shadow the terrain and enhance topographic relief.

2) LSAP is weather dependent and time-of-day dependent (i.e. it must be done in early morning or late afternoon hours).

3) LSAP is latitude dependent because in certain parts of the world suitable illumination will only be possible from a few select directions. Radar can image the terrain from any direction at any latitude.

4) LSAP does afford better scale stability and more accurate measurements can be made from it.

Suggestions For Future Use

In areas where the topography and the geology are reasonably well known, such as in most of the United States, radar imagery can have the following uses;

1) The mission can be used to test the sensor itself. In this study known geology and topography was compared to the imagery to establish guidelines for radar interpretation. This type of study should be done in many more areas.

2) The radar imagery of an area of known geology can be used to check the field mapped data as far as regional patterns of bedding and foliation and regional patterns fracturing are concerned. This is plausible because in so many cases a remote sensor can "see" what the field geologist can not.

3) Regional fracture patterns can be mapped on radar imagery quicker and more accurately than in the field.

4) The correlation between the lithology and topography can be tested in areas where the lithology is well mapped.

5) Anomalous areas or trouble spots in the field can sometimes be more clearly understood, or at least focused on, by using radar imagery

6) The revision of maps is facilitated and conflicting interpretations may be resolved.

In areas where the topography and the geology are not well known a radar study could have these advantages;

1) In many cases, whether due to weather conditions or extreme inaccessability, radar imagery may be the only view of the topography, let alone the geology, of an area. In these instances radar imagery provides a most efficient first view.

2) The topography of such areas could be qualitatively summarized at a glance and topographic maps, although crude and somewhat inaccurate, could be made.

3) Drainage maps could be constructed.

4) Regional type reconaissance geologic maps could be made showing;
   a) general lithologic distribution (based on relative resistance to erosion).
   b) regional structural trends.

c) fracture patterns.

5) Areas for field parties to investigate could be readily discovered.

6) Possibly, upon further refinement of radar systems, land use maps could be constructed.

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Appendix

Explanation and references for Plate I ("Geologic" map of Southern New England showing lithology and major faults.

Symbols

lithologic contact

high angle fault

low angle fault with T on upper plate

high angle fault with bar and bell on downthrown side

high or low angle fault showing relative motion

? ? ? contact in doubt

Notes on Explanation for "geologic" map of southern New England.

1. a,b and c numbered units are in Connecticut only

2. g numbered units are in Rhode Island only

3. d,e and f numbered units are in Massachusetts only

4. one unit may have two different letter-number codes if that unit crosses state borders

5. local names and ages have been omitted, the order of the units does not imply relative ages.

A4

a numbered units - eastern Connecticut

\- poorly foliated, quartz-feldspar mica schist,
calcite marble,
medium to coarse grained muscovite-biotite-garnet schist,
plagioclase-muscovite-biotite gneiss,
muscovite-garnet quartzite and quartz pebble conglomerate,
finely laminated, fine grained calc-silicate schist,
plagioclase-quartz-biotite-muscovite-microcline schist,
muscovite-biotite-staurolite-garnet-plagioclase schist,
chlorite-garnet schist,
plagioclase-amphibole-garnet schist,
graphitic mica-garnet-staurolite schist.

\- medium to coarse grained quartz monzonite ,
fine to coarse grained granite,
hornblende-biotite granite gneiss.

a3 - medium grained hornblende-biotite-plagioclase-quartz gneiss.

a4 - fine to coarse grained biotite-hornblende-plagioclase-quartz diorite,
medium grained, thickly layered plagioclase-quartz-biotite-hornblende gneiss
and amphibolite.

a5 - massive to coarsely foliated feldspar-biotite-hornblende-muscovite granite gneiss,
schistose biotite-hornblende amphibolite.

a6 - coarse grained, massive to foliated, porphyroblastic biotite-muscovite granite
gneiss with massive to schistose hornblende lenses and amphibolite,
granodiorite gneiss.

a7 - medium grained muscovite-biotite-garnet-oligoclase-quartz schist,
muscovite-biotite-orthoclase-sillimanite-garnet schist,
garnet-quartz-biotite schist and amphibolite,
thin layers of calc-silicate gneiss.

a8 - quartz-plagioclase-biotite schist,
calc-silicate gneiss,
fine grained biotite-hornblende schist,
fine to medium grained, thinly layered biotite-andesine-quartz schist.

a9 - quartz-plagioclase-microcline gneiss with fine grained biotite interlayered
with amphibolite lenses,
granodiorite gneiss,
quartz monzonite gneiss.

a10 - garnet-biotite-muscovite schist,
biotite-sillimanite-orthoclase schist,
quartz-biotite-muscovite-feldspar gneiss,
calc-silicate gneiss,
garnet-quartz-biotite gneiss,
calcite marble,
hornblende-biotite-graphite-pyrite-sillimanite-quartz-feldspar gneiss and
amphibolite.

a11 - biotite-hornblende-quartz-plagioclase-microcline granite gneiss,
medium grained plagioclase-quartz monzonite gneiss,
porphyritic granite gneiss.

a numbered units - eastern Connecticut (continued)

aI2 - amphibolite,
quartz-feldspar gneiss,
minor amphibole-garnet gneiss.

aI3 - muscovite schist,
kyanite-staurolite-plagioclase-quartz-biotite schist.

aI4 - biotite-garnet-quartz-feldspar gneiss and schist with amphibolite,
biotite-sillimanite schist,
quartzite, feldspathic and micaceous quartzite and calc-silicate quartzite,
quartz-sillimanite-biotite-garnet gneiss.

aI5 - medium grained quartz-feldspar-biotite gneiss,
fine to medium grained quartz-oligoclase-microcline-biotite gneiss,
fine to medium grained amphibolite,
\- fine to medium grained quartz-feldspar granofels,
medium grained, porphyritic granite gneiss.

aI6 - hornblende-biotite gabbro
biotite diorite.

aI7 - medium grained oligoclase-orthoclase-quartz-biotite granodiorite gneiss,
quartz monzonite gneiss,
porpyhroblastic biotite-microcline-oligoclase-quartz gneiss.

aI8 - medium grained hornblende-biotite gneiss,
hornblende-andesine-labradorite gneiss and amphibolite,
medium grained, thinly layered quartz-epidote-biotite-andesine-hornblende gneiss,
fine grained, well layered calcite-biotite-hornblende-quartz-oligoclase schist with muscovite quartzite.

aI9 - fine to medium grained quartz-muscovite-biotite-oligoclase-andesine-staurolite-garnet schist

a20 - medium to coarse grained oligoclase-quartz monzonite gneiss

a2I - medium grained muscovite-biotite-microcline-oligoclase-quartz gneiss,
gneissoid quartz monzonite.

a22 - fine to medium grained, thinly layered quartz-plagioclase-biotite schist,
fine to medium grained biotite gneiss.

a23 - fine to medium grained biotite-sillimanite-garnet schist and gneiss,
graphitic-sulfidic gneiss,
calc-silicate schist and gneiss.

a24 - medium to coarse grained microcline-plagioclase-quartz granite.

a25 - sulfidic-graphitic mica schist,
feldspar-quartz-biotite-sillimanite-garnet schist, and gneiss.

a26 - coarse grained, porphyritic biotite-muscovite granite.

b numbered units - central Connecticut

b1 - unmetamorphosed conglomerate, arkosic sandstone and siltstone, and shale.

b2 - diabase intrusives.

b3 - basalt extrusives

c numbered units - western Connecticut

c1 - evenly banded quartz-feldspar-biotite gneiss.

c2 - coarse grained marble with dolomitic parts and layers of mica schist.

c3 - coarse grained quartz-biotite-muscovite schist and schistose gneiss,
sillimanite-garnet-biotite schist with quartzite layers.

c4 - garnet-sillimanite-biotite schist,
fine to medium grained mica quartzite,
coarse grained muscovite-quartz schist,
medium to coarse grained feldspar-biotite gneiss,
medium to coarse grained garnet-plagioclase-biotite-muscovite-quartz schist,
medium to coarse grained garnet-biotite-muscovite-quartz schist,
medium to coarse grained garnet-muscovite-microcline-quartz-plagioclase gneiss,
fine to medium grained muscovite-biotite-plagioclase-quartz granulite,
medium grained biotite-muscovite-plagioclase quartz schist,
hornblende-plagioclase amphibloite,
kyanite-sillimanite schist,
medium grained, massive biotite-quartz-feldspar gneiss.

c5 - quartz-hornblende-biotite gneiss.

c6 - foliated biotite granite.

c7 - layered hornblende gneiss and amphibolite

c8 - fine to medium grained biotite gneissic granite.

c9 - biotite-quartz gneiss to granitic gneiss.

c10 - coarse grained biotite-quartz gneiss,
feldspathic mica quartzite,
sillimanite-garnet-quartz-feldspar-biotite gneiss,
fine to medium grained quartz-plagioclase-muscovite-biotite gneiss,
poorly foliated sillimanite-kyanite-muscovite-plagioclase-quartz-biotite gneiss,
fine to medium grained quartz-plagioclase-biotite-muscovite schist.

c11 - banded granitic gneiss,
hornblende-biotite gneiss.

c12 - coarse grained calcite marble.

c13 - quartz diorite,
granodiorite,
quartz monzonite.

c numbered units - western Connecticut (continued)

cI4 - fine to medium grained, massive granite.

cI5 - fine to medium grained hornblende-biotite diorite gneiss.

cI6 - granulated granite gneiss.

cI7 - fine grained phyllite,
quartz-mica schist,
calcareous mica-quartz schist
schistose marble.

cI8 - biotite-garnet-sillimanite schist.

cI9 - fine to medium grained, layered microcline-biotite-quartz-plagioclase granite gneiss,
fine to medium grained, massive mica-microcline-quartz-plagioclase granite gn

c20 - fine to coarse grained, massive or layered granite and granite gneiss.

c2I - basalt extrusive

c22 - unmetamorphosed arkosic conglomerate and sandstone.

c23 - medium to coarse grained kyanite-garnet-biotite-plagioclase-muscovite-quartz schist.

c24 - medium grained, foliated biotite-quartz-microcline-plagioclase gneiss,
medium to coarse grained garnet-plagioclase-biotite-muscovite-quartz schist,
medium grained biotite-hornblende-quartz-microcline-plagioclase gneiss.

c25 - medium grained muscovite-quartz monzonite.

c26 - medium grained muscovite schist and gneiss interlayered with medium to coarse
garnet-biotite-chlorite-plagioclase-quartz-muscovite schist,
chlorite-sericite schist.

c27 - fine to medium grained greenschist and low grade amphibolite.

c28 - phyllitic schist interlayered with quartz gneiss.

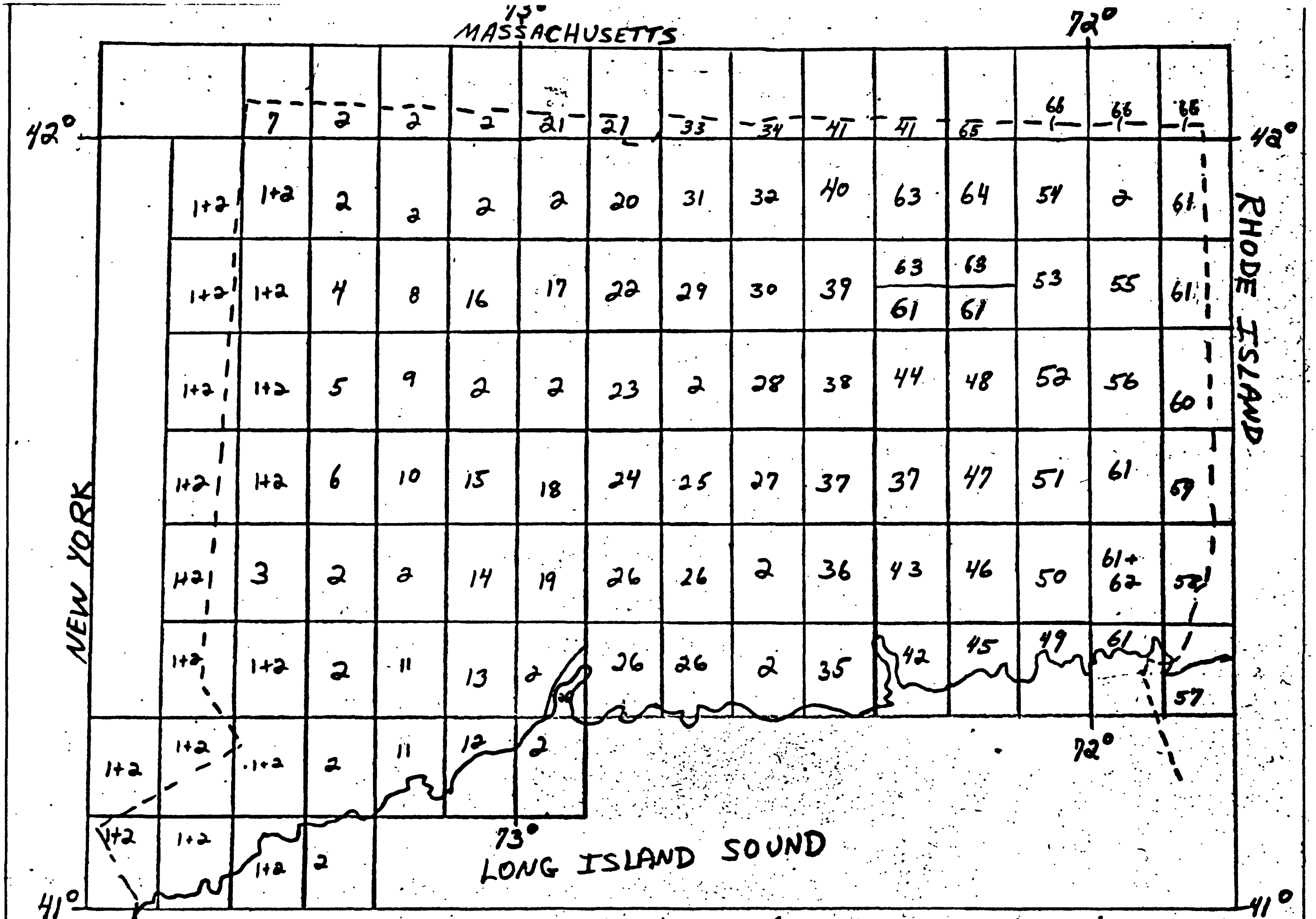
c29 - quartzite and biotite-muscovite schist interbanded with gneiss and quartzo-feldspathic material.

c30 - fine grained to pegmatitic, massive to layered granite.

c31 - medium to coarse grained kyanite-garnet-muscovite-biotite-plagioclase-quartz schist,
medium grained garnet-biotite-quartz-plagioclase gneiss.

c32 - medium grained garnet-plagioclase-mica-quartz schist,
fine to medium grained biotite-plagioclase-quartz gneiss.

c33 - biotite granite gneiss (partly layered).



REFERENCE GRID FOR CONNECTICUT — A-8

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d numbered units - eastern Massachusetts

dI - granite gneiss,
quartz-hornblende-biotite gneiss with minor quartzite,
medium grained, well foliated quartz-microcline-oligoclase-hornblende-biotite gneiss with minor amphibolite.

d2 - coarse grained biotite-garnet-muscovite-quartz schist.

d3 - fine grained hornblende schist with interbedded feldspathic quartzite.

d4 - quartz-muscovite-biotite schist,
feldspathic schist.

d5 - medium grained quartz-microcline-Na plagioclase-biotite granite to quartz diorite,
medium grained, well foliated quartz-Na plagioclase-muscovite-chlorite-biotite gneiss

d6 - fine grained, well foliated amphibolite,
thickly bedded micaceous graywacke and quartz schist,
mica schist,
medium grained quartzite.

d7 - granite, granodiorite, monzonite and quartz diorite.

d8 - coarse grained, massive to foliated, porphyroblastic biotite-muscovite granite gneiss with massive to schistose hornblende lenses and amphibolite,
granodiorite gneiss.

d9 - fine grained, layered quartz-feldspar gneiss,
hornblende gneiss and schist,
quartz-mica-sillimanite schist with minor amphibolite gneiss.

d10 - poorly foliated quartz-biotite-muscovite-plagioclase±garnet-staurolite-kyanite schist,
fine to medium grained calcareous granofels,
fine grained, thinly bedded micaceous quartzite.

dII - fine to medium grained, unfoliated quartz-plagioclase-biotite-muscovite-garnet granofels.

dI2 - fine to coarse grained, thin to very thickly layered quartz-garnet-orthoclase-plagioclase-biotite-sillimanite-cordierite gneiss and schist,
fine to coarse grained, thinly layered quartz-plagioclase-orthoclase-biotite-sillimanite-garnet gneiss interlayered with schist,
fine to coarse grained amphibolite,
medium to coarse grained, thin to thickly layered quartz-biotite-garnet-sillimanite-orthoclase-plagioclase gneiss,
fine to medium grained biotite-plagioclase-quartz gneiss,
fine to medium grained, thinly layered quartz-plagioclase-biotite-hornblende gneiss,
thinly layered, garnetiferous, sillimanitic, quartz-rich orthoclase-biotite gneiss,
fine to coarse grained, thin to thickly layered quartz-plagioclase-biotite-orthoclase-garnet gneiss,
fine to medium grained quartz-diopside-plagioclase gneiss,
fine to medium grained plagioclase-hornblende-diopside-quartz gneiss,
medium grained quartz-plagioclase-orthoclase-biotite-garnet gneiss.

d numbered units - eastern Massachusetts (cont.)

dI3 - graphitic mica schist and minor quartzite,
hornblende-epidote amphibolite,
interbedded quartz-plagioclase-biotite granulite and minor calc-silicate rock,
garnetiferous, feldspathic quartz-mica schist with sillimanite or staurolite,
fine grained, locally bedded quartz-feldspar gneiss,

dI4 - hornblende gabbro,
biotite quartz diorite, granodiorite and quartz monzonite.

dI5 - foliated mica-garnet-microcline granite,
biotite quartz diorite,
coarse grained, porphyritic granite,
coarse grained plagioclase-hornblende-biotite-hypersthene diotite,
medium to very coarse grained, gneissoid quartz monzonite, granite and granodiorite.

dI6 - calc-silicate schist.

dI7 - pegmatitic granite full of inclusions of dI2.

dI8 - biotite-quartz schist with calcareous, actinolitic lenses.

dI9 - pegmatitic granite.

d20 - muscovite-biotite granite.

d2I - slightly biotitic quartzite with calcareous lenses.

d22 - coarse grained, porphyritic biotite-muscovite granite.

d23 - graphitic phyllite and slate.

d24 - coarsely micaceous andalusite-garnet-chlorite-muscovite-staurolite schist.

d25 - biotitic gneisses and schists of sedimentary origin,
biotitic gneisses of probable igneous origin,
injection gneisses and bodies of highly altered limestone all with many granite dikes.

d26 - porphyritic granite gneiss.

d27 - quartzite interlayered with mica schist.

d28 - diorite and associated gabbro.

d29 - actinolitic quartzite, phyllite and slate.

d30 - granite and granodiorite,
medium grained, massive to foliated hornblende-biotite-oligoclase-quartz diorite.

d3I - quartz diorite.

d32 - quartz diorite gneiss,
coarse grained, porphyritic biotite-muscovite granite.

d numbered units - eastern Massachusetts (cont.)

d33 - diorite.

d34 - gabbro and diorite.

d35 - volcanic flows, breccias, tuffs,
shale.

d36 - biotite granite with blue quartz.

d37 - quartzites, conglomerates, sandstones and arkosic sandstones, graywackes, shales,
coal beds, felsites and felsite breccias.

d38 - slate

d39 - chlorite-hornblende-epidote-biotite schist interbedded with thin layers of
quartzite and quartz-muscovite schist,
minor limestone and conglomerate lenses.

d40 - alkalic granite

d41 - conglomerates, sandstone and slate.

d42 - volcanic flows, breccias and pyroclastic sedimentary beds,
intrusive felsites and granophyric rocks.

d43 - augite-hornblende syenite to gabbro.

d44 - granite, syenite and quartz syenite, and alkalic granites.

d45 - diabase dike.

d46 - fine grained, porphyritic granite.

d47 - massive argillite.
gd - glacial drift very thick - no bedrock outcrop.

e numbered units - central Massachusetts

e1 - arkosic conglomerate and sandstone,
coarse grained feldspathic sandstone,
shale, calcareous arkose, coarse conglomerate, talus breccia,
thinly bedded limestone.

e2 - basalt flows and flow breccia.

f numbered units - western Massachusetts

f1 - quartzose and micaceous phyllite,
conglomerate and quartzite,
carbonaceous phyllite and slate with thinly bedded limestone,
chlorite-sericite schist,
fine to medium grained mica-quartz-albite schist and schistose marble,
medium grained schistose quartzite and graphitic schist.

f numbered units - western Massachusetts (cont.)

f2 - calcite limestone,
fine to coarse grained marble with some dolomite,
feldspathic and schistose marble.

f3 - fine to medium grained, massive muscovite quartzite.

f4 - massive to thinly bedded quartz-feldspar-biotite-muscovite granulite and feldspathic quartzite interbedded with carbonates.

f5 - coarsely crystalline, massive, porphyritic granite gneiss.

f6 - biotite gneiss, biotite amphibolite and actinolite-epidote gneiss.

f7 - quartz-mica-albite schist,
albite-sericite schist,
medium grained quartz-plagioclase-mica gneiss and schist,
medium grained quartz-muscovite-plagioclase-biotite-garnet schist,
fine grained, carbonaceous quartz-mica gneiss.

f8 - fine grained quartzite and epidote-chlorite-quartz greenstone,
fine grained sericite-chlorite-chloritoid schist,
fine to medium grained quartz-muscovite-plagioclase schist,
fine to medium grained plagioclase-hornblende amphibolite,
medium grained, carbonaceous quartz-muscovite-plagioclase-biotite-garnet schist.

f9 - fine grained biotite granite gneiss,
medium grained, foliated, laminated microcline-plagioclase-biotite gneiss.

f10 - fine grained quartz-plagioclase-biotite schist,
fine grained quartz-muscovite-biotite-kyanite-plagioclase-garnet-chlorite schist,
fine to medium grained, schistose to massive plagioclase-hornblende amphibolite.

f11 - medium to coarse grained feldspar-quartz-muscovite-biotite-garnet schist,
medium to coarse grained mica-quartz-plagioclase-garnet schist and gneiss,
fine to medium grained muscovite-biotite-quartz-plagioclase-garnet-staurolite schist,
fine to medium grained quartz-muscovite-biotite-plagioclase-garnet schist.

f12 - feldspar-quartz-biotite granite gneiss.

f13 - medium grained, schistose to massive plagioclase-hornblende amphibolite,
fine grained, schistose to granular feldspar-quartz-biotite-muscovite-garnet schist,
fine grained, carbonaceous quartz-muscovite-biotite-garnet schist.

f14 - fine grained mica quartzite and quartz-biotite-garnet-muscovite schist,
fine to medium grained, massive to schistose, carbonaceous schist,
quartz-mica granulite,
fine to medium grained quartz-mica-garnet schist and phyllite,
calc-silicate rock,
garnetiferous quartz-mica schist interbedded with quartzite and marble,
amphibolite.

f15 - medium grained plagioclase-microcline-quartz-biotite-muscovite granite.

f numbered units - western Massachusetts (cont.)

f16 - feldspar-quartz-biotite gneiss.

f17 - phyllite interbedded with thin quartzite laminae,
argillite with quartzite, crystalline limestone and fine grained meta-tuff.

f18 - medium grained biotite-muscovite granodiorite.

f19 - medium to coarse grained hornblende-oligoclase-quartz-microcline biotite-chlorite quartz diotite.

f20 - phyllite with quartzite and limestone,
laminated meta-tuff,
quartz conglomerate,
amphibolite.

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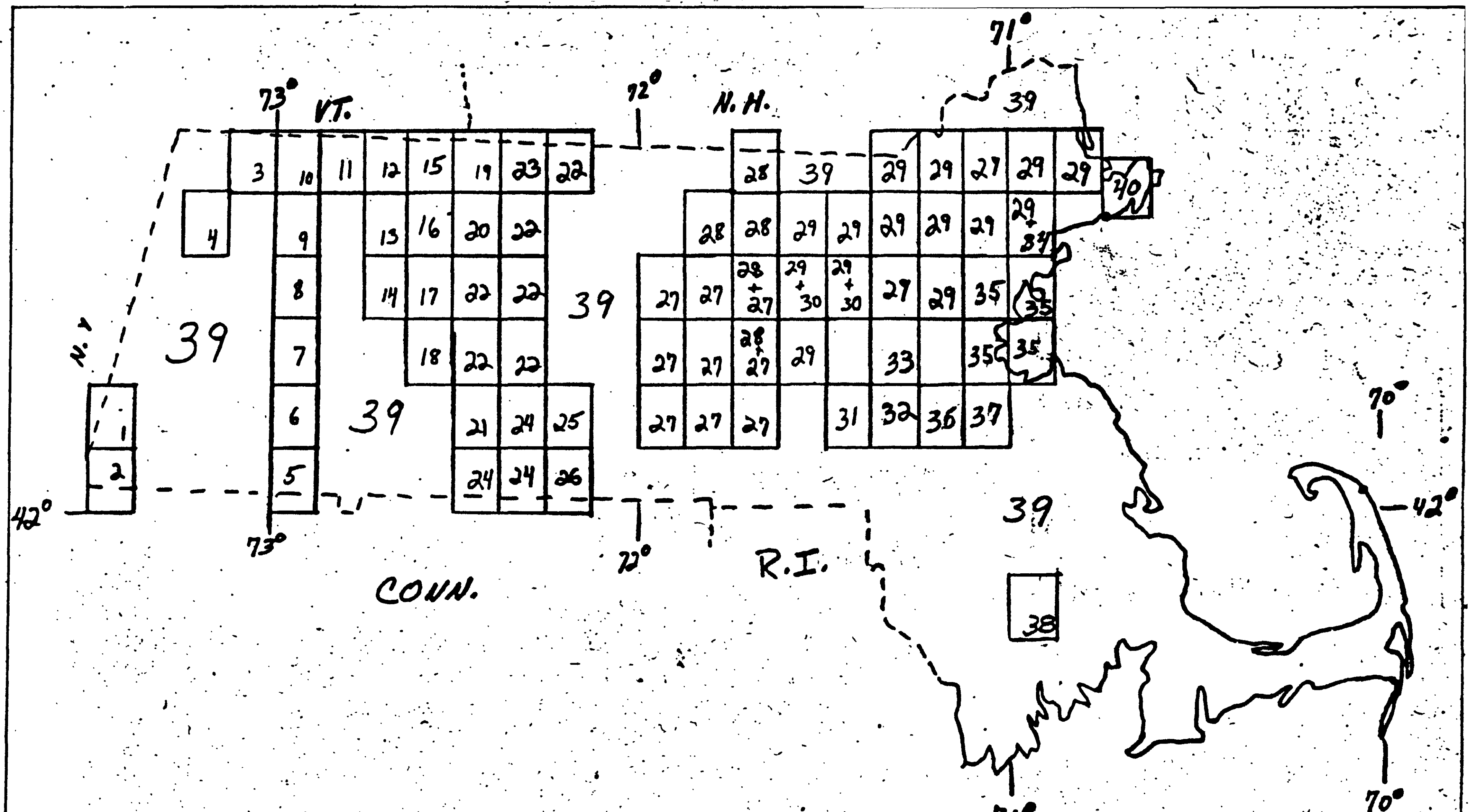

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g numbered units - Rhode Island

g1 - medium grained feldspar-quartz-biotite gneiss and schistose gneiss,
fine to medium grained quartzite,
medium to coarse grained, massive calc-silicate quartzite.

g2 - medium grained, massive, porphyritic quartz monzonite to granodiorite.

g3 - fine grained, schistose to massive quartz-mica schist,
quartzitic greenstone and marble (dolomitic and calcitic),
fine grained, thinly bedded chlorite-quartz schist,
fine grained, massive to schistose amphibolite,
plagioclase-epidote-chlorite greenstone.

g4 - fine to coarse grained sandstone, lithic graywacke, shale, conglomerate, meta-anthracite and phyllite.

g5 - fine grained, thinly bedded mica schist,
fine grained, poorly foliated chlorite-biotite-quartz schist,
volcanic tuff, conglomerate and slate.

g6 - medium grained microcline-albite-oligoclase-quartz gneiss.

g7 - porphyritic granite gneiss.

g8 - fine to medium grained microcline-albite-oligoclase-quartz-biotite granite gneiss.

g9 - medium to coarse grained microcline-plagioclase-quartz-biotite-hornblende-muscovite gneiss.

g10 - fine grained feldspar gneiss, schist, quartzite and amphibolite,
calc-silicate gneiss.

g11 - fine to coarse grained, massive to schistose diorite.

g12 - fine to medium grained microcline-oligoclase-quartz-muscovite gneiss,
medium to coarse grained biotite gneiss and schist.

g13 - medium to coarse grained microcline-albite-oligoclase-quartz-biotite granite gneiss.

g14 - granite gneiss.

g15 - medium to coarse grained microcline-albite-quartz-biotite granite.

g16 - medium to coarse grained microperthite-quartz-biotite granite.

g17 - coarse grained microperthite-microcline-albite-quartz-biotite-chlorite-muscovite granite.

g18 - fine to medium grained quartz-feldspar-biotite gneiss.

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