UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

EVAULATION OF REMOTE SENSING, GEOLOGICAL, AND GEOPHYSICAL DATA FOR SOUTH-CENTRAL NEW YORK AND NORTHERN PENNSLYVANIA

by

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U.S. Geological Survey
Open-File Report 82-319
1982

This report is preliminary and has not been reviewed for confirmity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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*Not included. Previously approved as U.S. Geological Survey Open File Report 79-533.

ABSTRACT

A study was made of the relationship between lineaments observed on Landsat satellite images and the geologic framework of a portion of the Allegheny Plateau of south-central New York and northern Pennsylvania. The area is underlain by a relatively thick sequence of salt and other evaporites in the Silurian Salina Group and is a potential site for deep-storage of solid nuclear waste. A combination of remote sensing techniques, detailed geologic mapping and geophysical investigations were applied to the problem. Because of the premature termination of the Department of Energy contract, only a portion of the total work was completed.

The completed portion of the project included 1) digital contrast enhancement of several Landsat multispectral scanner (MSS) images, 2) analysis of lineament patterns from a Landsat MSS-7 mosaic, 3) field mapping of bedrock joint patterns, 4) compilation and analysis of surface and subsurface structure and isopach maps, 5) collection and digital analysis of aeromagnetic data for southern New York, 6) compilation and analysis of aeromagnetic and gravity data for much of New York and Pennsylvania, and 7) analysis of seismic reflection survey lines for selected portions of New York and Pennsylvania.

We identified eight major lineaments or lineament zones and studied them in detail. They typically represent linear alignments of the most conspicuous or prominent physiographic features observable on Landsat images.

The Cortland-Ithaca, Watkins Glen-Tanghannock, Seneca Lake-Elmira, Painted Post-Blossburg and Endicott-Syracuse conspicuous lineaments include the Corning-Bath, Van Etten-Towanda, Van Etten-Candor and Van Etten-Odessa lineaments. In addition, a major fault system--the West Danby fault zone--was further defined by geologic and geophysical investigations during our study; the fault zone was not recognizable on satellite images. The lineaments and lineament zones were categorized by their azimuthal trends. Those with a northerly orientation (e.g. Van Etten-Towanda, Seneca Lake-Elmira, Painted Post-Blossburg and Endicott-Syracuse) are most common. Northeasterly lineaments (e.g. Cortland-Ithaca and Watkins Glen-Taughannock) also are common. The Corning-Bath and Van Etten-Odessa lineaments have a northwesterly orientation and the Van Etten-Candor lineament is the sole representative of the east-west direction. The West Danby fault system also trends east-west.

All the lineaments or lineament zones studied appear to be related, in one fashion or another, to structural disturbances, because changes in the structural attitude of beds or thickness of rocks commonly occur along their extent. The changes in many instances occur on multiple stratigraphic horizons and in a manner suggestive of several different styles of tectonism, leading to the conclusion that the lineaments and lineament zones have been periodically reactivated during the Paleozoic and Mesozoic Eras. Aeromagnetic data commonly show a parallel alignment of contours juxtaposed or on line with

lineaments and lineament zones, suggesting that these physiographic alignments owe their origin to features within the crystalline basement.

Pre-Alleghanian faulting and depositional patterns show that the study area was affected by basement-controlled adjustments along and in the same direction as most of the lineaments and lineament zones. Actual displacements cannot be proven for all of the lineaments or lineament zones, but changes in dip of the rocks across these features suggest either basement hingelines or small displacement faulting which cannot be resolved by the present data. These displacements occurred in at least Middle-Late Ordovician, Middle-Late Silurian and the Early-Middle Devonian times.

The major northeast trending lineament zones (Cortland-Ithaca and Watkins Glen-Taughannock) correspond in orientation and lie along the northeastward projection of the Rome Trough, a postulated Paleozoic aulacogen. Results of this study suggests that the two lineament zones are an expression of the Rome Trough and that the trough extends into New York. However, movements appear to have been more subdued than those which occurred farther southward in Pennsylvania and West Virginia.

Ordovician sedimentation patterns and faulting suggest that the north-trending lineaments (Painted Post-Blossburg, Seneca Lake-Elmira, Van Etten-Towanda and Endicott-Syracuse) also may be related to the northeasterly trending lineaments, implying that the main part of the trough may have died out in a series of faults of decreasing magnitude trending in the north and northeast directions.

The easterly trending features (Van Etten-Candor lineament and the West Danby fault system) appear to be related to sedimentational hinge lines, with stratigraphic units below the salt beds increasing in dip southward of the features into the Appalachian Basin.

The northwesterly trending features have the least supporting evidence for their relation to structure, however, limited evidence suggests that the Corning-Bath lineament is a major gravity discontinuity and appears as a hinge line or sedimentation trap affecting facies in some Ordovician and Devonian units respectively. The Van Etten-Odessa lineament is paralleled by a series of faults which exist only below the Silurian salt units and which are located about 3 km south of the lineament.

Thrust- and tear-faults are the dominant features of thin-skin tectonism associated with the Alleghany orogeny. The faults appear to be localized along those lineaments and lineament zones which have preferred directions with respect to the northerly directed compressional forces of the orogeny. Northerly trending lineaments (Painted Post-Blossburg, Seneca Lake-Elmira, Van Etten-Towanda, and Endicott-Syracuse) developed above tear faults or ramps, whereas the single documented easterly trending lineament (Van Etten-Candor) is associated with thrust faulting. The West Danby fault system also is composed of a series of forward and antithetic thrusts and defines the northern extent of a relatively thick Silurian Salina "F" salt unit. Subsurface and outcrop data were insufficient to ascertain the relationship of the northeasterly and northwesterly trending linear features to Alleghanian structures.

Ultrabasic intrusives of Jurassic-Cretaceous age appear to be localized along or at the intersections of some of the lineaments or lineament zones, attesting to the deep crustal origin of these linear features.

ACKNOWLEDGEMENTS

The authors wish to thank Richard Beardsley, Columbia Gas Corporation, Charleston, West Virginia for access to unpublished seismic refraction surveys in the study area. We wish to thank Wallace deWitt, USGS, for access to unpublished stratigraphic and structural data for Devonian rocks of the region. We are especially grateful to William Diment, Otto Muller and Peter Lavin for permission to use and publish their preliminary Simple Bouger gravity map of Pennsylvania. Conversations and the suggestions of Wallace deWitt, Leonard Harris, Ernest Muller, Robert Coates, William Diment, Russell Wheeler and Yngvar Isachsen among others are gratefully acknowedged. This work was supported by interagency agreement #DE-A197-79ET 44611 between the U.S. Department of Energy and Department of Interior.

INTRODUCTION

This report describes the results of a study of the regional structural framework of a part of the Allegheny Plateau in south-central New York and adjacent northern Pennsylvania (fig. 1). The primary objective of this study was to use remote sensing techniques for identification of surface features that might relate to subsurface structures and that might affect the integrity of salt beds at depth. Another objective was to develop methods for analyzing remote sensing data in conjunction with conventional surface and subsurface data specifically for regional geologic evaluations of potential waste disposal sites.

The surface of the study area is a gently rolling upland dissected by glacially modified valleys. Elevations above sea level range from approximately 122m (400 feet) to 671 m (2200 feet) with local relief of as much as 305 m (1000 feet). A variable thickness of glacial till and outwash blankets the area and the soils developed on these units support a dense cover of mixed hardwood and coniferous trees.

Predominantly clastic Middle Devonian through Pennsylvanian rocks are exposed in the study area; the units are generally warped into east to east-northeast trending broad, open folds (Pennsylvania Geological Survey, 1960; Rickard and Fisher, 1970). Sparse exposures and a paucity of marker beds have, prior to the present study, led to a generally simple picture of the near surface structure.

Our study indicates considerable structural complexity in the area, including several previously unrecognized fracture zones, however, regional syntheses and analyses of the data are incomplete as the project was prematurely terminated in 1979.

METHODS OF STUDY

Our study is predicated on the genetic relationship between landforms, the lithology of the stratigraphic sequence, and the structures that deformed the rocks; it also hinges on the demonstrated value of analyzing satellite images for studying this relationship. Alignments of linear segments of streams and valley walls are the dominant erosional landforms in the study area. Therefore, we emphasized analysis of these linear features on the assumption that they represent lines or zones of structural breakage or dislocation.

Lineament studies first were conducted using digitally enhanced Landsat Multispectral Scanner (MSS) images for the area, which is underlain by thick units of subsurface salt of the Silurian Salina Group. The area, situated between latitude 41°45 N - 42°30 N and longitude 76°W - 77°W, is referred to as the local study area (fig. 1).

Although constraints imposed by the Department of Energy (Brunton and others, 1978), especially depth to salt, limit the practically prospective area to north of latitude 42°7'30"N, the region to the south was investigated because of the need to gather data peripheral to the area for structural analysis and because future advances in mining technology might allow for deeper burial.

In order to assess the relationship between the local structure and regional tectonic patterns, we studied a broader area using a mosaic of conventional MSS images (figs. 2a & b). This broader area lies between latitude 41°N - 43°N and longitude 75°30'W - 78°15'W (fig. 1).

Several types of images were used, including high-altitude aircraft and Skylab color and color-infrared photographs, Heat Capacity Mapping Mission (HCMM) images, side-looking radar images, and Landsat 3 Return Beam Vidicon (RBV) images. However, most of the images were either of poor quality or obscured by partial cloud cover, and the project terminated before analysis of the better quality images could be completed. Consequently, these other data sources will not be discussed.

Analysis of surface and subsurface information formed the base for evaluation of the structural significance of the lineaments delineated in the Landsat MSS images. Surface data include structure contours, regional trends of folds and joints, the distributions of pencil siltstones and anomalous dips of bedding planes. Subsurface information consists of well log data, structure contour and isopach maps, gravity and aeromagnetic maps, and proprietary seismic reflection surveys.

The discussion that follows presents descriptions of the methods used in individual aspects of the study and then describes the evidence for and postulated origin of eight major lineaments. Detailed description of some elements of the study are given in Appendices A-F.

IMAGE ENHANCEMENT

A computer-enhanced Landsat image (fig. 3) was produced for the local study area of the Salina basin in south central New York. Digital image processing was done at the USGS National Center, Reston, Virginia using the REMAPP image processing programs (Sawatzky and Townsend, 1976); details of the computer processing, contrast enhancement and film playback are given in Appendix A. The computer-enhanced image was generated from a MSS band 7 half frame with 100 micron pixels, producing an image scale of 1:787,500 (fig. 3).

For the regional analysis, eight MSS band 7 enlargements were combined at an approximate scale of 1:750,000 into an uncontrolled mosaic that covers south-central and western New York State and adjacent northern Pennsylvania (figs. 2a & b). In making the mosaic, 11 x 14 inch photographic enlargements of Landsat MSS band 7 images were used, because such hand-developed prints could be produced quickly, yet commonly show more detail than standard prints from the EROS Data Center. We chose winter images with minimum snow cover because lower sun angle and lack of foliage contribute to enhancement of topographic features. Although the uncontrolled mosaic does not have precise geometry or scale, it is useful for identifying regional geologic features.

COMPILATION OF LINEAMENTS

Lineaments (O'Leary and others, 1976) were compiled by two interpreters using the digitally enhanced MSS 7 image (fig. 3) of the local study area and the uncontrolled MSS 7 mosaic of the broader region (fig. 2a). In both compilations, all linear features were mapped including those which might coincide with cultural features. The rationale for this procedure was to avoid omission of cultural features which might follow morphological features that are related to geologic structures. Thus, a linear stream valley that contained a recognizable road would not be ignored in the compilation. An arbitrary 0.25 cm. lower limit of length was followed in both compilations.

Two procedures were used for compiling the lineaments on the enhanced MSS 7 image and the photomosaic. In Procedure I, through-going features were delineated even though they might be locally discontinuous. So long as the distance separating the linear segments was small relative to the total lengths of the segments, the feature was considered through-going. Procedure II involved mapping only those linear features which were distinctly continuous in their expression on the images.

The purpose of a dual approach was to determine which of either methods would produce mapped features that more clearly relate to surface and subsurface structural data. Certain Soviet authors have long considered (e. g. Trifonov and others, 1978, p. 188-190) that longer through-going lineaments express deep, regional structural disturbances, such as deep basement faults in platform areas, whereas shorter lineaments, although they also might be related to deep crustal features, more commonly relate to such local features as local faults or joints. We have not tested these premises in any rigorous fashion, however, we can present strong circumstantial evidence relating the lineaments mapped by Procedure I to some known and some inferred deep seated, possibly reactivated faults.

Procedures I and II were applied to a contrast-enhanced Landsat MSS band 7 half-scene centered our local study area (figs. 3, 4, & 5). Procedure I was applied to the Landsat MSS-7 photomosaic (figs. 2a and 6).

ANALYSIS OF LINEAMENTS

Analysis of the lineaments proceeded from examination of individual lineaments in the local study area (fig. 4) to determine their relationships with landforms, direction of movement of Pleistocene glacial ice, joints, and cultural features to a statistical analysis of the lineaments and finally, to a discussion of eight major lineaments delineated on the MSS photomosaic of the broader area (figs. 6 & 7). The eight major lineaments were chosen on the basis of their prominence and their geographic relation to the local study area. Only the lineaments delineated using Procedure I are discussed.

Stream valleys account for 80.9% (301 observations) of the lineaments on the MSS 7 image of the eastern half of the local study area (figs. 4 and 8). The preponderance of stream valley lineaments was expected, as even a cursory examination of the image shows that the majority of linear features are due to streams. Cliffs and ridges not directly associated with stream valleys account for 7.2% (27 observations) of the lineaments (fig. 8). The cliffs and ridges are either not related to present stream valleys or are widely separated from the present stream courses.

Lineaments in the local study area with no topographic or cultural control accounted for 9.4% (35 observations) of the total lineaments (fig. 8). Only 2.4% (9 of 376 lineaments) represent cultural features with no related topographic control (fig. 8).

As discussed in Appendix B and shown in figure 9, the correlation of lineaments with joints was not expected to be very high although previous studies concluded that the drainage pattern was dictated largely by joints. However, only 4.6% (17 out of 376 observations) of the lineaments in the local area studied occur within ten degrees of either of the two major joint directions. Lineaments whose orientations are within 10 degrees of the strike of glacial striae accounted for 23.3% (87 observations) of the total. Clearly, as in the case of the orientation of stream valleys, correlation of joints with lineaments is poor and a better correlation between lineaments and directions of ice movement is indicated.

The 506 lineaments delineated on the MSS photomosaic of the broader study area (figs. 2a and 6) were digitized and recorded on computer-compatible tape to facilitate statistical analysis using the LINANL programs (Sawatzky and Raines, in press). The analysis is incomplete because of the premature termination of the study; that portion completed is included as Appendix C of this document. A brief summary of the more salient results follows.

The statistical examination of the frequency-azimuth distribution shows that broad ranges of azimuths were statistically significant. This result differs from other studies (Sawatzky and Raines, in press) which found that relatively narrow azimuthal ranges could be defined by this technique.

We believe that the causes for this dichotomy are geologically related. Although the study area is large, the number of linear features detected per unit area is relatively small. This effect may be attributable to the extensive glacial cover and vegetation, which may have masked many existing linear features present in the underlying bedrock. The resultant small sample size of lineaments (506), thus may have served to subdue the peaks and troughs of the frequency-azimuth distribution and the algorithms in the LINANL programs may not be suitable for such sample sizes. Prior applications of LINANL procedures have been limited primarily to the western U.S., where bedrock exposures occupy a greater proportion of an area, vegetation is relatively sparse and glacial masking is a relatively minor factor. Another possible cause is the mixing of geologically different populations of lineaments. These population differences might be caused by the geographic exclusivity of certain trends (i.e. the preferred position of certain lineament trends on a particular lithology), or the lineaments themselves may be the manifestation of several different structural features and their interactions (i.e. joint zones, faults, etc.). Yet another possible geologic cause might be related to the apparent continual directional shift in some of the trends, most notably in the NNW-N trends, which appear to swing with the curvature of the Appalachian orogen where it changes from a salient to a recess in north and northeast Pennsylvania. Further research is required to determine the precise cause.

Two possible biases may have been introduced in the data: sun angle illumination and the scan line direction. Both would result in detection of fewer lineaments in the northwest to west-northwest directions. We believe the sun illumination angle bias undoubtedly exists, but cannot judge its extent. Other images using some illumination angle other than Landsat's southeasterly direction could be examined to test this hypothesis. The minima in the azimuth-frequency histogram do coincide with the directions which ought to be underrepresented.

Four combined azimuthal peaks and one trough were defined by the statistical process, although one peak could be broken into three subsets. Some of the trends could be readily ascribed to specific phenomena. The $334^{\circ} - 357^{\circ}$ and $11^{\circ} - 20^{\circ}$ trends are related to lineaments which strike nearly normal to the direction of the Alleghanian fold axes. Lineaments trending normal to folds have been termed cross-structural discontinuities (Wheeler and others, 1979) and are found throughout the folded Appalachians. Another trend ($72^{\circ} - 79^{\circ}$), although smaller in frequency, trends parallel to the fold axes. The other trends, the $307^{\circ} - 330^{\circ}$, $20^{\circ} - 66^{\circ}$ and $80^{\circ} - 90^{\circ}$ peaks and the $270^{\circ} - 306^{\circ}$ trough, cannot be readily ascribed to Alleghanian structures.

The number of lineaments present in each significant azimuthal trend precludes a detailed investigation of each individual. Representative lineaments have been chosen from each of the major peaks for more detailed examination. By this method we hope to demonstrate the veracity of the lineaments, and by inference, suggest that others of the same azimuthal trend and in close proximity to the studied linear features are genetically related.

Lineaments studied in detail were divided into two classes. Those linear features which have a continuous or nearly continuous expression in the image are referred to as lineaments, whereas a lineament zone consists of a series of aligned discontinuous features. The lineaments examined in detail are illustrated in figure 7. These include the Corning-Bath and Van Etten-Odessa lineaments of the 307° - 330° peak and the Endicott-Syracuse, Painted Post-Blossburg, Seneca Lake-Elmira lineament zones and Van Etten-Towanda lineament of the 334° - 357° trend. The Cortland-Ithaca and Watkins Glen-Taughannock lineament zone is representative of the 11° - 66° trend. The 72° - 79° trend is represented by the Van Etten-Candor lineament.

SUMMARY OF PREVIOUS GEOLOGIC STUDIES

Exposed rocks in the study area are mainly Middle Paleozoic clastic sedimentary units which regionally dip gently southward and become progressively younger in the direction of the Appalachian basin (Hall, 1839, 1843; Vanuxem, 1842). Both Hall and Vanuxem also noted local flexures in individual outcrops or groups of outcrops, but it was not until Kindle's work (Kindle, 1904; Williams and others, 1909) that these flexures were synthesized at a quadrangle level. Wedel (1932) used outcrop data in creating the first regional structure map of the Allegheny Plateau of New York. He noted that although anticlines and synclines were regional in their extent, they contained local inflections and domes, basins, and saddles along their axes. Wedel also concluded that 1) structural amplitude of the folds increases markedly from north to south, 2) the folds have a nearly E-W strike between longitudes 75°45'W and 77°15'W, 3) they die out rather abruptly between the longitudes of 75° 45'W and 76°W and 4) the fold axes either change strike rather abruptly from E-W to S40°W - S60°W or lose their continuity between the longitudes of 77°W and 77° 15'W. Wedel (1932) agreed with Kindle (1904) and correctly concluded that the folds in New York and the folded Appalachians to the south shared the same structural origin. He speculated that the folds were propogated concentrically from some Cambro-Ordovician level, or perhaps basement, thus favoring a "thick skinned" origin for the folds.

Since Wedel's work, the regional subsurface structure has become better known due to petroleum exploration activity. Compilations of structural and stratigraphic maps are available for the Cambro-Ordovician rocks (Rickard, 1973), selected Ordovician and Silurian units (McCann and others, 1968) and the

Silurian Salina Group (Rickard, 1969). Well data for these units are relatively sparse, particularly in the study area, because the units have been considered either too deep or unproductive for hydrocarbons. Shallower formations, those above the Salina Group, are better known, although they too lack good data in the present study area, mainly due to poor reservoir capacities in the normally productive horizons.

The Lower Devonian Oriskany Sandstone has been mapped regionally by several workers (Fettke, 1933; Finn, 1949; Fettke, 1954; Cate, 1961), as have rocks of the Onesquethaw Stage of Lower and Middle Devonian ages (Oliver and others, 1971; Mesolella, 1978). The Middle Devonian Tully Limestone has also been studied in some detail (Heckel, 1973; Wright, 1973; deWitt, unpublished data). Numerous detailed studies have also been completed on a quadrangle or local basis for surface or near surface units within the study area (Bradely and Pepper, 1941; Humes, 1960; Nugent, 1960; Twigg, 1961; Woodrow, 1968).

Based on his studies, Fettke (1933) postulated a major decollement within the Silurian Salina Group on the Allegheny Plateau. Rodgers (1949) expanded this idea and suggested that major thrust faulting, mainly within the Salina Group, appeared to be prevalent under large portions of the Allegheny Plateau of Pennsylvania and West Virginia. A concept of "thin skinned" tectonics has held sway since then, although Cooper (1961) has suggested some basement control.

Gwinn (1964), in a well documented study of thin-skinned deformation from central Pennsylvania southward into West Virginia, showed from subsurface data that most thrust faulting in the Ridge and Valley Province and Allegheny Plateau was taken up along fracture zones associated with decollements and splay faults within incompetent rocks. In the Ridge and Valley Province, major decollements occur in Cambro-Ordovician shales and in parts of the Allegheny Plateau, in Silurian salt beds. Moreover, Gwinn showed that the surface folds commonly vary in amplitude, strike and/or pitch where the decollements change their stratigraphic horizon by ramping. These changes in surface geometry of the folds commonly occur along linear zones transverse to the trends of the folds and have been ascribed to tear faults (Rodgers, 1963, 1970) and ramps (Wilson and Stearns, 1958; Gwinn, 1964; Harris, 1970; Kowalik and Gold, 1976).

Closer to the present study area, Rodgers (1964) pointed out several alignments of Alleghenian fold truncations, which he suggested were due to pre-Alleghenian tectonism and basement control. These zones of aligned fold truncations are both oriented approximately north-south. Rodgers defined one of the zones as the eastward truncation of the Nittany anticlinorium at Williamsport, PA (W, fig. 2a). Based on deflections of anticlinal axes in the Plateau, he tentatively extended the zone northward to the Finger Lakes area, between Keuka and Seneca Lakes (Rodgers, 1970). Rodgers (1964) also noted the peculiar and abrupt termination of the east end of the Lackawanna syncline (L, fig. 2a) as well folds to the south. Not only does the east end of the syncline abruptly die out, but its axial trace is markedly deflected to the north. At that time (1964), Rodgers postulated a rather nebulous structural line between Albany, NY to a point somewhere along the Schuylkill River in eastern Pennsylvania, along which a number of structures die out, including the Lackawanna Syncline. His later text on Appalachian tectonics (Rodgers, 1970) makes no mention of this alignment.

SUMMARY OF GEOLOGIC AND GEOPHYSICAL DATA USED IN THIS STUDY

Introduction

Besides the above works, little has been done to elaborate a regional structural synthesis for the study area. The data exist for such a synthesis, and we will show that the lineament patterns derived from the satellite images correspond to some of the previously postulated structural discontinuities. Furthermore, we believe that the lineament patterns, in conjunction with the surface and subsurface geology and geophysical data, have allowed us to define major tear faults in the Allegheny Plateau, and that at least some of these tear faults and associated thrust faults can be related to recurring movements along structural discontinuities in the basement.

Surface Stratigraphy

Outcrops in the study area consist mainly of Middle to Upper Devonian interfingering siltstones and shales that become progressively younger to the south. Regional stratigraphic correlations are difficult, not only because of the extensive glacial cover and vegetation, but also because this area lies at the transition between the thick sequence of coarse clastic rocks of the Catskill facies to the east and thinner, equivalent and more laterally extensive marine rocks to the west. Few laterally continuous key beds crop out, except for the Middle Devonian Tully Limestone at the northern edge of the study area. Attempted stratigraphic correlations have been based on thin beds of black shale or conglomerate which are commonly discontinuous.

Figure 10 shows a composite stratigraphic correlation chart for surface units present in the study area. Because of the stratigraphic problems mentioned above, this column is given only so that readers may familiarize themselves with the relative sequence of units that will be discussed; it is not offered as a solution to the stratigraphic controversy in the area.

Subsurface Geology

A generalized stratigraphic column for the area, including some of the more important subsurface units, is shown in figure 11. The subsurface geology has been summarized for individual periods, series, stages or units by Fettke (1954), Rickard (1969, 1973), Oliver and others (1971), Mesolella (1978), Zerrahn (1978) and others. In contrast to outcrops, rocks in the subsurface provide many distinctive and laterally extensive stratigraphic units. These include the Devonian Tully Limestone and Onondaga Limestone and the Oriskany Sandstone in the sequence above the Salina Group. The Silurian Lockport Dolomite, Medina Sandstone and the Ordovician Trenton Group are excellent key units below the salt beds of the Salina Group. Considerable information is available in well logs, subsurface structure maps, and seismic reflection surveys to help interpret the subsurface structural geology of the region.

Unfortunately, as mentioned earlier, most drilling has been limited to the shallow formations above the Salina Group, such as the Tully Limestone and Oriskany Sandstone. Structural control below the salt beds is lacking, particularly in our local study area south of the Finger Lakes.

Isopach and Structure Contour Maps

We studied structure contour and isopach maps for numerous beds above, within, and below the Silurian salts. We shall cite evidence for most units investigated, but only maps for selected units are illustrated. Included are isopachs on the Upper Cambrian - Lower Ordovician Sauk Sequence of Sloss, Krumbein and Dapples (1949) (Rickard, 1973) (fig. 12), Ordovician Trenton carbonates (Rickard, 1973) (fig. 13) and a structure contour map on top of the Trenton Group (Rickard, 1973) (fig. 14). Structure contour and isopach maps of the Upper Silurian Salina Group are presented for the B, D-E and F units (Rickard, 1969) (figs. 15-17). The terminology for the Salina Group is a variant of that instituted by Landes (1945) for the Michigan basin. Suprasalt units are represented by isopachs of the Lower Devonian part of the Onesquethaw Stage (Mesollela, 1978) (fig. 18) and Tully Limestone (Wright, 1973) (fig. 19).

Geologic investigations have shown that many lineaments are related to faulting (Isachsen, 1976; Gold, 1977; Hunter and Parizek, 1979; Pattridge, 1979; Thompson and Hager, 1979). Unfortunately, subsurface structural data are relatively sparse in our study area, allowing only broad generalizations to be made about the structure of a given geologic unit, particularly for units below the Salina Group.

Isopach and facies maps are essential for analyzing paleotectonic activity (Harris, 1978; Shurr, 1979; Simpson, 1979). These data help to screen out the effects of the later tectonic episodes, in this instance, the Alleghanian Orogeny. For example, areas of consistently thin formations may imply elevation either during deposition or elevation and erosion shortly after deposition. Conversely, thickened sections may mark loci of deposition. Consequently, relatively subtle changes in thickness or facies of stratigraphic units may reflect a structural influence. Some consistent relationships between isopach and facies data and lineaments can be demonstrated in this study.

Structural Form-Line Maps

A regional map of anticlinal axes was compiled (fig. 20) based on the works of Wedel (1932) and Fettke (1954). We have compiled a form-line map for our local study area based on published and unpublished data, relating all horizons to a common datum plane, the top of the Upper Devonian Pipe Creek Shale (fig. 21).

A structure contour map is usually based on one horizon, in contrast to the form-line map, which contains data from numerous horizons. The form-line map is useful where data from any one horizon are sparse, but numerous stratigraphic units and their intervals are mapped. Such is the case in our study area, where due to the dip of the beds, units crop out for short distances normal to strike and well data are insufficient to map their subsurface positions. Because of the wide range of thicknesses of stratigraphic units and the exact stratigraphic correlations applied by the sources utilized in this compilation, the form-line map will be inherently less accurate than a structure contour map. However, the map does offer a local synthesis of structural information previously not available for the area.

Glacial Features

Glacial valleys are perhaps the most significant features which are manifested as lineaments. Therefore, the question of structural control on the development of the glacial valleys is critical to this study. Glaciated valleys are oriented in two primary directions; N50^{o} to 75^{o}E, from an earlier Pleistocene ice advance which was deflected southwestward by the Catskill Mountains (Coates, oral commun., 1978) and N10^{o}W to N10^{o}E, which represents a later southward advance from the Ontario basin (Muller, oral commun., 1978). Most of the broad valleys in the study area are either oriented along directions of primary ice movement or are connecting "through valleys" sculptured by ice moving between valleys aligned along primary ice-movement directions.

Even though some authors have attributed the valley directions to primary action by glaciers (Clayton, 1965), most workers in the area feel that the valleys originated by fluvial action in pre-glacial times (Coates; Fullerton; and Muller; oral comm. 1977, 1978), and that these fluvial valleys were subsequently modified by glaciation. We concur with these latter opinions.

Joints

Joints are infrequently parallel to the stream valleys (see Appendix B), but change their trends commonly in the vicinity of major lineaments. We believe that this change in strike is due to structural discontinuities between regional blocks which moved differentially.

Pencil Siltstones

Acicularly cleaved siltstones (Cloos, 1946), termed "pencil siltstones" (Engelder and Geiser, 1979), are thought to be related to regional deformation in those areas where folding has taken place without associated faulting (Engelder and Geiser, 1979). Our investigations in New York State and independent studies in Pennsylvania by one of us (H. Pohn) show that in seven areas, pencil siltstones occur relatively near known faults. In several other areas, outcrops of pencil siltstones have been found in which the strike of the pencils is nearly parallel to the strike of inferred faults.

Engelder and Geiser (1979) reported pencil siltstones oriented parallel to Allegheny fold axes. We have found more variable orientation to pencil siltstones, but they are most frequently either parallel to or perpendicular to the fold axes. We believe that the pencil siltstones are related to either thrust or tear faults and their long axes roughly parallel the trend of the controlling fault. Additional discussion can be found in Appendix D.

Anomalous Bedding Dips

In the study area, bedding dips greater than 3° are rare. We considered dips of more than 5° anomalous, and dips of as much as 10° are almost certain indicators of faulting. At many localities, we found steep dips near existing faults.

Gravity and Aeromagnetic Maps

Bouger gravity anomaly maps for New York (Revetta and Diment, 1971; Simmons and Diment, 1973; Diment and others, 1973; Urban and others, 1973) and Pennsylvania (Muller and others, 1979; Muller and others, unpublished data) were mosaicked (fig. 22). The compiled map of Pennsylvania is preliminary, as terrain corrections of as much as four milligals are necessary for some data in the north-central portion of the state (Diment, pers. comm., 1980). Aeromagnetic maps of total intensities were mosaicked for central and western New York (U.S. Geological Survey, 1975, 1977, 1979) and adjusted to a statewide aeromagnetic map of Pennsylvania (U.S. Geological Survey, 1978) (fig. 23). Digital aeromagnetic data also were modeled for portions of New York. Interpretation of the digital data is included in Appendix E.

Seismic Reflection Surveys

We used several proprietary seismic reflection surveys from various sources to determine the subsurface expression of selected lineaments (see Appendix F). In addition, detailed coverage was purchased and evaluated for the Van Etten, NY area, where salt thickness is greatest. Coverage included the Van Etten-Candor, Van Etten-Towanda and Van Etten-Odessa lineaments. Structure-contour maps based on two-way travel time to a specific reflector were constructed for the top of the Cambrian Theresa Dolomite, Ordovician Trenton Limestone, Silurian Lockport Dolomite, Devonian Onondaga Limestone and Tully Limestone. Isopach maps of the total interval between the tops of the Onondaga Limestone- Lockport Dolomite and Trenton Limestone-Theresa Dolomite were created based on these seismic reflection data. The maps derived from these data are presented in Appendix F.

DISCUSSION OF SELECTED LINEAMENTS

Introduction

The following selected lineaments are typically parts of larger patterns. Thus, if the cause of one lineament can be demonstrated, we may imply that others of that pattern have similar genesis. Table 2 summarizes the geological and geophysical evidence for each feature discussed.

TABLE 2 - SUMMARY OF GEOLOGICAL AND GEOPHYSICAL EVIDENCE FOR LINEAMENTS DISCUSSED IN TEXT*

LINEAMENTS &/or FAULTS / GEOLOGICAL or GEOPHYSICAL CRITERIA	CORTLAND ITHACA	WATKINS GLEN-TOUGHANNOCK (2)	CORNING-BATH (3)	VAN ETTEN-TOWANDA (4)	SENECA LAKE-ELMIRA (5)	PAINTED POST-BLOSSBURG (6)	ENDICOTT-SYRACUSE (7)	VAN ETTEN-CANDOR (8)	VAN ETTEN-ODESSA (9)	WEST DANBY FAULT
Precambrian (P€)	NE projection on line with Adirondack fault	See Cortland-Ithaca		no data	no data	N projection on line with graben faulting	no data	detail insufficient	detail insufficient	detail insufficient
€-O (Saukian sequence)				no data	possible isopach inflection along northward extension			"	"	"
Trenton carbonates	Parallel to isopachs; also see P€	See Cortland-Ithaca	Parallel to isopachs	no data	Parallel to isopachs	Same as P€ parallel to isopachs	Parallel to isopachs	"	"	"
Upper Ordovician units	NE projection on line with isopach inflections	on line with zone of thickening	possibly parallel to isopachs	no data		possible inflections in isopachs		"	"	"
Vernon "A" unit				no data	possible facies change	possible facies change		"	"	"
Vernon "B" unit	possibly on line with litho-facies change	See Cortland-Ithaca		no data	possible isopach alignment along south projection			"	"	"
Vernon "C" unit	possible inflections in isopachs	See Cortland-Ithaca		no data	isopach inflections			"	"	strong inflection on isopachs
Syracuse "D&E"	on line with axis of thickest salts	See Cortland-Ithaca		no data	parallel to isopachs tear faulting parallel	possibly parallel to isopachs	parallel to isopachs	"	"	parallel to isopachs
Syracuse "F" Unit				no data	marked isopach inflections wedge of thick salt block	parallel to isopachs	parallel to isopachs Edge of thick salt block	"	"	parallel to isopachs N edge of salt block
Camillus & Bertie ("G&H")	possibly parallel to isopachs	See Cortland-Ithaca		no data	parallel isopachs and thickening	strong isopachs inflections	parallel to isopachs	"	"	parallel to isopach inflections
Lower Onesquethaw fm.	SW projection on line with zero edge	See Cortland-Ithaca		SW projection parallels isopachs	on zero edge thickening to east			"	"	faulting
Total Onesquethaw fm.	isopach inflections along SW projection	See Cortland-Ithaca	Facies "embayment" along south end of lineament	SW projection parallels isopachs	on zero edge thickens to east			"	"	faulting
Tully lms.	SW projection divides thick & thin Tully	See Cortland-Ithaca	possible thickened zone along lineament	inflections in isopachs	possible zone of isopachs inflections		parallel to zero edge	"	"	faulting

*A blank space indicates no corraborating evidence.

TABLE 2 - SUMMARY OF GEOLOGICAL AND GEOPHYSICAL EVIDENCE FOR LINEAMENTS DISCUSSED IN TEXT* (continued)

LINEAMENTS &/or FAULTS GEOLOGICAL or GEOPHYSICAL CRITERIA	CORTLAND ITHACA	WATKINS GLEN-TOUGHANNOCK (2)	CORNING-BATH (3)	VAN ETTEN-TOWANDA (4)	SENECA LAKE-ELMIRA (5)	PAINTED POST-BLOSSBURG (6)	ENDICOTT-SYRACUSE (7)	VAN ETTEN-CANDOR (8)	VAN ETTEN-ODESSA (9)	WEST DANBY FAULT
Surface structural form map	no data	no data	parallel to structure contours	inflections-complex closures	zones of marked change in bedrock strikes		no data	no data	no data	shows fault
Anticlinal Axes	no data	no data	marked inflection of axes	anticlines change plunge & strike	marked deflection in axes & loss of closures	termination of structure & inflection of axes	axes die out along lineament	parallel to strike of folds		parallel to strike of folds
Bedrock Joints	no data	no data	joints change strike across lineament			joints change strike across lineament	joints change strike across lineament			possible deflection of joint trends
Glacial	primary glacial direction	primary glacial direction		primary glacial direction	primary glacial direction	primary glacial direction	primary glacial direction	primary glacial direction	through valley	not applicable
Pencil Siltstones	no data	no data		7 occurrences parallel to lineament	5 occurrences parallel & near lineament		4 occurrences parallel to lineament			pencil siltstones along trend of faults
Anomalous Bedding Dips	no data	no data								3 sets of anomalous dips correspond to two forward thrusts & one antithetic thrust
Aeromagnetic Data	lineament parallel to contours; possible basement graben	same as Cortland-Ithaca	lineament parallels local trends; possible shear zone	subtle inflections in closures; basement fault	lineament parallel to regional contours; no faulting in basement	lineament parallel to regional contours; possible faulting in magnetic basement	lineament parallel to aeromag highs; deeper magnetic basement west of lineament	possible alignment; downfaulting to south in magnetic basement	lineament parallels regional trends to N; parallel to flank of basement dome	east-west basement disruption
Gravity Data	parallel to contours, SW projection aligned with large gravity gradient	See Cortland-Ithaca	parallels local trends		parallel to regional gravity gradient	subtle gravity truncations	subparallel to contours	parallel to gravity data	parallels regional trends to north	lineament parallel to contours
Seismic Lines	possible offsets	strike & offsets confirmed		salt thickens east of lineament	basement increase in depth from W to E across lineament		possible change in depth to basement	thrust faults above salt; possible change in basement dip across lineament	subsalt faulting parallel south of lineament	basement dip increase from N to S
Misc.							subparallel to Middle Ordovician erosional unconformity; possible left-lateral shear zone	parallel and near W. Danby fault		surface faulting

* A blank space indicates no corraborating evidence.

Cortland-Ithaca and Watkins Glen-Taughannock Lineament Zone

The Cortland-Ithaca and Watkins Glen-Taughannock lineaments trend in the same direction and are in close proximity to each other. We believe that they are tectonically related and together they may represent the northwest and southwest boundaries of a broad lineament zone. Hence, we will treat them as one zone and evidence cited in this section will generally apply to this broader lineament zone, although some facts will refer specifically to one of the lineaments.

The Cortland-Ithaca lineament (see figs. 2a, 6 and 7) is a major lineament trending about N55^{o}E whose surface expression is mainly an alignment of glacially modified stream valleys. The lineament is nearly continuous from a point 40 km (25 miles) northeast of Cortland, southwest to Cayuta, NY, for a total distance of 80 km (50 miles). Although the lineament is not continuous beyond these limits, discontinuous linear features lie along its projection both southwestward into north-central Pennsylvania and northeastward to the Adirondack Mountains. Geophysical evidence supports both projections.

The Watkins Glen-Taughannock lineament lies approximately 16 km (10 miles) northwest of and is subparallel to the Cortland-Ithaca lineament (see figs. 2a, 6 and 7). The lineament can be followed on the surface for about 74 km (46 miles) from Painted Post on the southwest to Locke, NY on the northeast, and is expressed as a set of discontinuous, aligned, parallel to subparallel linear stream valleys, such as Hector Falls, Meads and Hemlock Creeks. Its discontinuous nature is due in part to the Finger Lake valleys, which interrupt what might otherwise be a single topographic lineament.

Structure contours on both the Precambrian (Rickard, 1973) and Trenton (fig. 14) surfaces show a northeast trending arcuate fault, downdropped to the northwest, along the lineament zone's northeast projection onto the Adirondack Dome. Also in this same area, aeromagnetic data (fig. 23) show pronounced alignments of contours coincident with the lineament zone, either related to the faulting or to changes in basement lithology. Interpretation of digital aeromagnetic data within the study area suggests a basement graben in the position of the lineament zone (Appendix E, p. E9 & fig. E-15), however, drillholes reaching basement are non-existent in this area to verify the interpretation. An isopach map of the Late Cambrian - Early Ordovician Sauk Sequence (fig. 12) shows no inflections along the lineament zone. Isopachs of the Middle-Upper Ordovician Trenton carbonate rocks (fig. 13) show a gradient parallel to and along the lineament zone within our study area, with carbonate rocks thickening to the north and west of the zone, and contemporaneous Utica shale thickening to the south and east. The Upper Ordovician Oswego Sandstone is thicker along the lineament zone (McCann and others, 1968).

In the Ithaca area, just southeast of Cayuga Lake and along the Cortland-Ithaca lineament, a seismic reflection survey shows a possible disturbed zone in the Silurian Lockport Dolomite and the Ordovician Trenton Limestone (see Appendix F). The geophysical evidence, however, is ambiguous, because it may actually relate to another nearby lineament, the north trending extension of the Van Etten - Towanda lineament.

Three seismic reflection surveys lines cross a portion of the Watkins Glen - Taughannock lineament between Seneca and Cayuga Lakes. (Appendix F, p. F5-F6, fig. F-6). Two of the three lines show basement related faults breaking the carbonates in the Ordovician Trenton Group and the younger Silurian Lockport Dolomite. The third line shows faults from the basement only up to the Trenton Group. The inferred strike of the faults is parallel to the lineament; estimated displacement is about 24 meters (80 feet), down to the southeast. None of the faults can be unequivocally shown to break the Upper Silurian Salina Group.

In the Upper Silurian Salina Group, a facies change in the "Vernon B" unit, involving addition of anhydrite to a predominantly shale and dolomite section, lies parallel and in close proximity to the lineament zone (Rickard, 1969, plate 5). Also, zones of thick salt are parallel or subparallel to the lineament zone in the "Vernon B," "Syracuse D-E," and "Syracuse F" units (figs. 15-17). Mesolella (1978) points out that the depocenters of the salts migrated southeastward from the time of deposition of the "Vernon B" through "Syracuse F" units. Particularly, the "Syracuse D-E" and "Syracuse F" units appear to be directly controlled by the lineament zone.

The Lower Devonian Oriskany Sandstone shows an area of zero isopachs (Fettke, 1954) centered on a gravity maximum (the Kane Gravity High of Diment and others (1980); K on fig. 22); the southeast boundaries of the zero isopachs and the Kane Gravity High both parallel the southwestward projection of the lineament zone. Rocks of the Early Devonian Onesquethaw Stage (Oliver and others, 1971) thin in the same fashion as the Oriskany Sandstone. Pinnacle reefs in the Lower Devonian Onondaga Limestone are aligned in northeasterly trends in this same area (deWitt, pers. comm, 1979). The Middle Devonian Tully Limestone shows a conspicuous flattening of the isopach gradients northwest of the lineament zone (fig. 19).

The lineament zone lies along a major gravity gradient (fig. 22), which is most pronounced in northern Pennsylvania, along the southwestward projection of the lineament zone. Here the gravity gradient separates high values (>-40 milligals) to the northwest (the Kane Gravity High; K - fig. 22) from low values (<-60 milligals) to the southeast (T - fig. 22). The gravity minimum corresponds to the axis of the Rome Trough as defined by Harris (1978), an aulacogen active throughout Early and Middle Paleozoic time, but most active during the Ordovician. Harris suggests that the trough was a graben in its early and most active stages, with high angle faults bounding it on the northwest and southeast. The position and trend of the high angle faults bounding the northwest side of the graben correspond to the steepest gravity gradient (-50 to -40 milligals) along the linear gradient and to our southwestward projection of the lineament zone. Parrish (1978) modeled gravity data for the Kane Gravity High and the associated gravity trough to the southeast. On the basis of his models, he postulated a set of vertically displaced basement blocks becoming structurally lower to the southeast off the gravity high. Harris (1978) shows that the trough behaved more as a downwarp in post-Ordovician time.

We suggest that the lineament zone formed by the Cortland-Ithaca and Watkins Glen-Taughannock lineaments is a regional structural discontinuity. The zone is the surface manifestation of the high angle faults cutting basement based on: 1) exposures to the northeast on the Adirondack Dome, 2) postulated stratigraphic evidence and seismic and aeromagnetic surveys within our study area, and 3) stratigraphic evidence, seismic surveys and gravity modeling to the southwest. The evidence cited above suggests that the lineament zone within the study area was tectonically quiescent in the Late Cambrian and Early Ordovician, but formed a depositional trap through faulting, thus influencing sedimentation in Late Ordovician through at least Middle to Upper Devonian time. Within our study area, its effects were most pronounced in Ordovician time. Trenton carbonates are thickest to the northwest of the lineament zone, whereas contemporaneous Utica Shale is thicker to the southeast (Rickard, 1973). A thicker section of Oswego Sandstone also was localized along the lineament zone. We believe that the facies changes, migration of depocenters and stratigraphic thinnings and pinchouts both within our study area and more dramatically, to the southeast, are due to the systematic downwarping of the Rome trough along step-like down-to-southeast faults on the northwest side of the trough. Minor vertical adjustments along northeast trending faults may be responsible for the migration of the "salt basins" with time, localization of the Onondaga reefs, and areas of thin or absent Devonian units.

Harris (pers. comm., 1980) speculates that the Rome Trough changes to a more easterly direction in northern Pennsylvania. We contend that although this may be true, the trough may bifurcate, with subsidiary troughs controlled by relatively small amplitude faults trending northeastward and northward. Parrish (1978) showed that most of the known ultrabasic intrusives within Pennsylvania tend to be localized along a northeasterly trend corresponding with the northwest boundary of the Rome Trough. He speculates the peridotites were further localized where cross-faults intersect the bounding faults of the trough and points out examples in Pennsylvania. Three clusters of ultrabasic rocks are located in New York along Parrish's northeasterly trend. These include the dikes and sills of the Ithaca and Meyers areas, and a postulated intrusive south of Corning at the Pennsylvania border which Vozoff (1951) interpreted from gravity studies (Lawrenceville Gravity High, L-fig. 22) These three occurrences not only lie along our lineament zone, but we postulate that they are localized in these specific areas by two north-trending sets of linear features, the Painted Post Blossburg lineament zone and Van Etten-Towanda lineament, which are discussed elsewhere in this paper. The occurrence of ultrabasic rocks along the postulated bounding faults of the Rome Trough, where they are transected by cross-faults, suggests that the faults bounding the trough must be deep seated, because they appear to tap rocks of a mantle origin.

Alleghanian faulting cannot be conclusively related to the lineament zone within our study area because of the paucity of detailed stratigraphic data. Where faulting can be seen in seismic survey data, resolution appears insufficient to resolve breaks which may exist.

Corning-Bath Lineament

The Corning-Bath lineament extends N40°W from approximately 6.5 km (4 miles) southeast of Corning, to Cohocton, NY, at its northwest extremity, a distance of approximately 61 km (38 miles) (figs. 2a, 6 and 7). It is mainly a topographic lineament formed primarily by the valleys of Cohocton Creek, and at its southeastern extremity, the Chemung River. With a change in azimuth to N60°W near Painted Post, NY, the lineament could be extended as a zone farther southeastward for an additional 55 km (34 miles), terminating at the south-trending Susquehanna River valley.

There are scant subsurface data to indicate structural control of this lineament. Isopachs of the Upper Ordovician Trenton carbonates (fig. 13) show inflections parallel to the lineament. Lower and Middle Devonian rocks of the Onesquethaw Stage feature a long and narrow tongue of more shaley limestone surrounded by carbonates parallel to and immediately south of the lineament (Oliver and others, 1971). This clastic sequence also is thicker to the south of the lineament. Structure contours on the Devonian Tully Limestone show an increased dip to the southwest of the lineament (Wright, 1973).

The surface formline map (fig. 21) shows a northwesterly alignment of contours along the lineament, in marked contrast to the general easterly structural trend east of the lineament's southeastern terminus near Corning, NY. Unfortunately, no reliable outcropping stratigraphic datum exists for the area in which the supposed change in strike occurs (deWitt, pers. comm., 1979).

The same changes in trends of structure contours seen in the Upper Devonian surface units are also seen in the subsurface map of the Lower Devonian Oriskany Sandstone (Fettke, 1954), although data are relatively sparse even for this well-known drilling target.

The surface traces of the Alleghanian fold axes (fig. 20) change azimuths from southwest to more southerly in a series of inflections occurring at or within 5 km (3.1 miles) of the lineament. Some axes also terminate in the same region. At the surface, joint trends change strike across the lineament, (Pohn, unpubl. data). The axial trace and joint data cited above for this lineament is located primarily around Corning, NY, where several lineaments, the Corning-Bath, Painted Post-Blossburg and Seneca Lake lineaments, may either intersect or interact. Thus, the evidence cited may be a reflection of any one or all of these lineaments and cannot be related positively only to the Corning-Bath lineament. Beardsley (Geophysicist, Columbia Gas Transmission Corp., Charleston, W.Va., pers. comm.) points out that seismic sections in the Painted Post-Corning area are all but uninterpretable because of severely disrupted nature of the deeply-buried key beds, suggesting massive structural dislocation in the subsurface.

A map of two-way travel time to basement (fig. 24) shows no measureable offset along the Corning-Bath lineament, although control is sparse to the northeast and unavailable immediately to the southwest of the lineament.

Aeromagnetic data (fig. 23) show the lineament superposed on two aeromagnetic maxima. The steep northeast and southwest gradients from these maxima are subparallel to the southeastward projection of the lineament. Interpretation of the digitally processed aeromagnetic data suggests a possible basement shear zone along the lineament (Appendix E, p. E11).

Gravity data show the lineament subparallel to and superposed on a gravity minimum with steep gradients to the northeast and southwest (fig. 22). The southeasterly projection of the lineament separates a local gravity maximum from the regional minimum (W - fig. 22) associated with the thick Salina salt sequence. The local maximum, known as the Lawrenceville Gravity High (L - fig. 22), has been interpreted as a peridotite intrusive at depth (Vozoff, 1951). Diment and others (1980) recognized the same linear trend which we associate with the Corning-Bath lineament. Their recognition was based solely on gravity alignments and they defined the trend as a longer feature extending from the Clarendon-Linden fault system on the northwest (CL - fig. 22) to the Scranton Gravity High on the southeast (S - fig. 22). They speculate that the seismicity in western New York, predominantly west of our study area, may be related to their gravity lineament and its intersection with the well-known Clarendon-Linden fault zone.

Based on the rather meager evidence cited for this lineament, we believe that the Corning-Bath Lineament is probably related to basement faults having inconsistent senses of movement along their length, perhaps indicating a shear zone. Seismic reflection survey evidence which does exist cannot be unequivocally attributed to any one of several lineaments which converge in the area of Corning, NY. The associated thinning of Trenton carbonates and facies changes in the Devonian Onesquethaw Stage sediments suggests a structural control. The change in strike of the Upper Devonian rocks from east-west to northwest, paralleling the lineament, are also suggestive of a structural control. Although no direct structural interruptions of the Silurian salt sequence were noted, the inflections and terminations of Alleghanian folds may reflect structural ramps and tear fults within the salts, similar to those noted by Gwinn (1964) in Pennsylvania.

Van Etten-Towanda Lineament

The Van Etten-Towanda lineament trends N10^{o}W from Towanda, PA at its southern extremity, to Van Etten, NY in the north for a total distance of approximately 47 km (29 miles) (figs. 2a, 6 and 7). It is expressed by the valleys of Cayuta Creek in the north and the Susquehanna River in the south. With an offset of about 4 km (2.5 miles) to the east along the Van Etten-Candor lineament (to be discussed later), the trend may be extended 35 km (22 miles) farther northward along the valleys of Catatonk Creek, Cayuga Inlet and the southern reaches of Lake Cayuga (figs. 2a, 6 and 7). Based on a series of discontinuous linear features south of Towanda, PA, the lineament may be projected southward out of study area to the vicinity of the southwest termination of the Lackawanna Syncline (figs. 2a, 6 and 7). Valleys comprising the lineament's northern extent lie along the primary glacial direction of ice advance from the Lake Ontario basin and were doubtless modified by glaciers.

Little well data are available for the area of the lineament and those data which exist are mainly for units above the salt sequence. The southward projection of the lineament in Pennsylvania is marked by a zone of isopach lines parallel to the lineament for rocks of the Early Devonian part of the Onesquethaw Stage (fig. 18). Rocks of the Onesquethaw Stage are thicker and predominantly clastic east of this zone whereas those west of the zone are thinner and predominantly carbonates (Oliver and others, 1971). In New York, (deWitt, unpubl. map) shows a saddle developed in the structure contours on the Tully Limestone where the lineament transects the Van Etten anticline, a regional east-west trending Alleghanian fold.

Structurally, the Van Etten-Towanda lineament is expressed at the surface as a series of inflections in the axial trends of the regional anticlines (fig. 20); the surface structural formline map (fig. 21) shows a series of structure contour inflections all along the lineament but which are most notable in Pennsylvania.

From Van Etten to Towanda, seven localities of pencil siltstones occur in which the siltstone cleavage is subparallel to the lineament, suggesting lineament-related faulting. At the south end of the lineament, near Towanda, an eighth occurrence of pencil siltstones has the acicularity oriented east-northeast, which corresponds both in position and strike to a series of thrust faults to the north of the Barclay syncline (B, fig. D-3, Appendix D).

Seismic reflection surveys in the vicinity of Van Etten, NY (Appendix F, figs. F-8 - F-15), were compiled into two-way travel time maps for several conspicuous reflector horizons. Time contours show relatively strong inflections along the strike of the of the Van Etten-Towanda lineament south of the village of Van Etten, suggesting a down-to-the-east fault underlying the lineament. Rocks as old as the Cambrian Theresa Dolomite are affected, and the fault probably extends to the Precambrian crystalline basement.

An isopach on the difference in travel time between the Silurian Lockport Dolomite and Devonian Onondaga Limestone, which includes the Upper Silurian Salina Group (fig. F-14, Appendix F), indicates a thinned salt sequence immediately southeast of the village of Van Etten. Isopach lines are oriented north-south to the east of Van Etten and are parallel to and overlying the Van Etten-Towanda lineament. Time contours on top of the Ordovician Trenton Limestone (fig. F-12, Appendix F), Silurian Lockport Dolomite (fig. F-11, Appendix F), Devonian Onondaga Limestone (fig. F-10, Appendix F) and overlying Tully Limestone (fig. F-9, Appendix F) all show abrupt deflections along the lineament.

The postulated northward extension of the lineament along Catatonk Creek north of Spencer, NY, is substantiated by the sharp inflections on top of the same units. Again, displacement appears to be down to the east.

Gravity data (fig. 22) show no variations which might be correlated with the lineament; local structurally related anomalies are probably overwhelmed by the negative anomaly produced by the thick Silurian salt block centered here. Aeromagnetic data (fig. 23) show subtle inflections and localization of closed contours along the lineament in both New York and Pennsylvania.

At the north end of the mapped extension of the Van Etten-Towanda lineament, at Myers, NY, an aeromagnetic anomaly (M - fig. 23) lies at the intersection with the Watkins Glen-Taughannock lineament. The aeromagnetic maximum may correlate with the kimberlite dikes and sills of the area (Sheldon, 1927; R. Rinkenberger, Mine Safety and Health Agency, 1978, pers. comm.) dated as Jurassic-Cretaceous (Zartmann and others, 1967). About 10 km (6 miles) south of Ithaca, NY, a large amplitude intensity aeromagnetic maximum (D - fig. 23) lies along the north extension of the Van Etten-Towanda lineament. The aeromagnetic maximum may reflect the buried source of the peridotite dikes which intrude north-south oriented joints about 1.6 - 6.4 km (1 - 4 miles) south and east of Ithaca. (Maartens, 1924; Sheldon, 1927; Rickard and Fisher, 1970). The dikes also lie directly on or within 6 km (3.7 miles) of the Cortland-Ithaca lineament. Small inflections in aeromagnetic contours occur along the lineament southward from Van Etten (V - fig. 23), with a more conspicuous inflection 6 km (3.7 miles) south of the southernmost mapped portion of the lineament (inflection of the 1000 gamma contour in Pennsylvania, fig. 23).

Interpretation of digitally processed aeromagnetic data (Appendix E) reveals magnetic basement downdropped to the west. The reversed sense of movement when compared to Paleozoic marker horizons may indicate contrasting juxtaposed rocks in the basement, as might occur if shallow basement west of the lineament contained a less magnetic lithology such as granitic rocks or metasediments. Although the precise cause is conjectural, an anomaly exists in basement rocks, attesting to a deep-seated cause for the lineament.

Although the strike of the joints shows no obvious deflections across the lineament, the average angle between the two major joint sets decreases slightly in the Van Etten quadrangle. This cannot unambiguously be attributed to the Van Etten-Towanda lineament inasmuch as the Van Etten-Candor and Van Etten-Odessa lineaments all intersect within the quadrangle.

Based on the cited evidence, we believe that the Van Etten-Towanda lineament and its northward extension along Cayuga Lake is the surface expression of a deep fault system. We speculate that several styles of faulting are present along the lineament and that movement may not have occurred simultaneously along the whole fault system.

Most likely, the lineament originates in the basement, based on the displacement of Cambrian through Middle Silurian units down-to-the-east in New York and interpretation of aeromagnetic data along the lineament. Isopachs of Lower to Middle Devonian rocks suggest that the area east of the lineament in Pennsylvania behaved as a downwarp prior to the Alleghanian Orogeny, isolating clastics to the east and predominantly carbonates to the west. The great differences in sediment thickness suggest that depositional control was along a hingeline controlled by faulting, similar to those faults which bound the Rome Trough. Hence, we infer that at least part of the Pre-Alleghanian tectonism was governed by vertical tectonics.

We also believe that Alleghanian deformation used the pre-existing zones of weakness along the lineament. The behavior of stratigraphic units above the salt, particularly the highly faulted Onondaga Limestone, suggest that the Van Etten-Towanda lineament may be a tear fault or a ramp. Evidence includes the plunging out of anticlines and synclines along the lineament, particularly in Pennsylvania, in a style shown by Gwinn (1964) and Harris (1970) to be typical of thin-skinned tectonics. The faults mapped by seismic reflection surveys on the Onondaga Limestone at Van Etten, NY are typical of a thrust-backthrust pattern of the faulting on the Allegheny Plateau. We further suggest that the tear fault has been translated eastward about 5 km (3 miles) along the Van Etten-Candor lineament (to be discussed later) and continues northward at least to Cayuga Lake. We cannot, however, rule out the possibility of vertical tectonics playing some part in the deformation of the salt and overyling formations.

Whether the salt has been thickened by tectonic or depositional mechanisms cannot be ascertained. We tend to favor a model in which the salt was regionally thickened in part by basin subsidence, but that the majority of the local aberrations in salt isopachs are due to thrust faulting. Mesolella (1978) shows a general ESE shift across New York of the Upper Silurian-Lower Devonian depositional basins. Small vertical movements along northeast or north trending fault systems could be responsible for such a migration. Prucha (1968) and Jacoby and Dellwig (1974) demonstrated that in the Ithaca and Watkins Glen areas respectively, salt thickness can vary dramatically due to thrust faulting or possible non-tectonic plastic flow.

Seneca Lake - Elmira Lineament Zone

The Seneca Lake-Elmira lineament zone strikes approximately N20°W, and is expressed discontinuously in the topography, consisting of portions of Seneca Lake and the valleys of Catherine Creek, the Chemung River and South Creek, respectively north to south, for a total distance of 80 km (50 miles) (figs. 2a, 6 and 7). The linear form of Seneca Lake, although primarily attributable to glacial excavation, suggests that the zone could be projected northward along the entire length of the lake.

Scant subsurface data are available for units below the Salina Group in the vicinity of our lineament zone.

A map of depth-to-basement (fig. 24) based on two way travel times derived from proprietry seismic reflection surveys on both sides of the lineament zone indicate a possible .05 second offset on basement, with the block on the east side of the lineament downdropped. The data are consistent with a north trending fault. It might be argued that the thickened salt sequence to the east (fig. 17) provides a velocity anomaly which gives an apparent offset. However, salt has an equal or higher velocity than the predominantly clastic section present here. Consequently, a thicker salt section should actually cause an upward displacement of the basement, rather than the observed increase in basement depth. Using an average velocity of 3050 meters/second (10,000 ft/sec.), we suggest that basement may be displaced downward about 76 m (250 ft.) to the east of the lineament zone.

An inflection of the 100 and 200 foot isopachs of the Cambro-Ordovician Sauk Sequence (fig. 12) occurs north of Seneca Lake, on the northward projection of our lineament zone. Isopachs of the Ordovician Trenton carbonates depict a thickening immediately east of the north end of Seneca Lake. Neither of these stratigraphic anomalies can be projected southward into our study area with any confidence inasmuch as no well data exist here for these two units. However, the apparent thickening of these two units to the east of the lineament zone suggests a basement control of the two units. The Upper Silurian Vernon "A" unit shows a facies change from gray and green shales with minor amounts of red shale to the west and predominantly red shales to the east (Rickard, 1969, pl. 4) along a line located 7 km (4.5 miles) west of and parallel to Seneca Lake and our lineament zone. Isopachs on the Vernon "B" unit show an increased gradient along the southern projection of the lineament in Pennsylvania (fig. 15). The Vernon "C" unit displays a conspicuous inflection in the 300 foot isopach at the lineament zone (Rickard, 1969, pl. 6). The Upper Silurian Syracuse "D-E" unit exhibits isopach contours subparallel to the lineament (fig. 16).

Jacoby and Dellwig (1974) document thrust faults with an implied east-west strike and infer a tear fault oriented north-south in the subsurface Syracuse "D" unit along the west side of the south end of Seneca Lake. Their inferred tear fault lies along the Seneca Lake-Elmira lineament zone. The upper part of the Syracuse Formation ("F" unit, fig. 17) shows relatively sharp inflections in salt isopachs in the vicinity of the lineament zone, with a parallel alignment of isopachs from the West Danby anticline, just southeast of the south end of Seneca Lake, southward to at least the New York-Pennsylvania border. The Upper Silurian Camillus Shale and Bertie Limestone isopach map (Rickard, 1969, pl. 9) shows an elongate north-south oriented thickened zone bounded on the east by the Seneca Lake lineament and on the west by the projection of the Painted Post-Blossburg lineament.

Cate's (1961) structure contour map on the top of the Oriskany Sandstone shows faulting on both sides of the south end of Seneca Lake. Displacement is down to the lake, suggesting a graben structure. An isopach map of rocks of the Early Onesquethaw Stage shows a zero isopach coincident with the lineament; rocks of this stage are absent to the west (fig. 18). Isopachs of the total Onesquethaw Stage depict a thickened section along the lineament, with thinning to both the east and west (Oliver and others, 1971). The Tully Limestone is marked by isopach inflections along the extent of the lineament south of Seneca Lake (fig. 19).

The surface structural formline map (fig. 21) also shows down-to-lake faults parallel to the lineament and bounding both sides of Seneca Lake, suggesting a north-south oriented graben in the area near Watkins Glen, NY. Marked inflections in structure contours are coincident with the lineament along its southward trace. The map of anticlinal axes (fig. 20) shows marked inflections of axial trends and some structures plunging out in the proximity of the lineament; the phenomena are particularly evident in anticlines south of Seneca Lake. Anticlines traversing the lineament zone change their strike from generally east-west east of the zone, to mainly northeast-southwest west of the zone.

The gravity map (fig. 22) shows an obvious gravity minimum (values <-60 milligals) associated with the thick salt sequence, most notably displayed by the "F" unit (fig. 17), bounded on the west by the Seneca Lake - Elmira lineament zone. The Simple Bouger gravity contours parallel the trend of the lineament, particularly near the New York-Pennsylvania state boundary. Along the northward projection of the lineament zone, an elongate gravity maximum with its long axis oriented northeast (values -40 to -30 milligals) is bisected into two local low amplitude highs with 4 milligal closure and still farther northward, the lineament defines the boundary between an area of relatively low gradients to the west and higher gradients to the east. A southward projection of the lineament zone into Pennsylvania shows it lies along a gravity "saddle" between two lows. The low to the northeast shows the dominance of the thick salt sequence mentioned earlier, whereas the southwesterly low presently is enigmatic, but may be related to the Rome Trough. More speculatively, farther southward into central Pennsylvania, the projection of the lineament zone truncates the southwest extremity of the Scranton Gravity High (Diment and others, 1972), isolating the high from the smaller gravity high to the southwest.

The aeromagnetic map (fig. 23) depicts magnetic-contour alignments with the lineament zone along and to the west of Seneca Lake. Interpretation of the digitally processed aeromagnetic data (Appendix E) reveals no obvious offsets of magnetic basement along the lineament zone, suggesting that if offsets do occur, they are of relatively small magnitude. A series of aeromagnetic highs aligned parallel to the northeast trending Watkins Glen-Taughannock lineament appear to be cut by the Seneca Lake-Elmira lineament zone. The northeast trending elongate gravity high previously mentioned in this section is in part coincident with the aeromagnetic anomaly. The aeromagnetic high at Myers, NY, along the Watkins Glen-Taughannock lineament previously herein has been attributed to an intrusion of ultrabasic rocks localized at the intersection of the lineament with the northward extension of the Van Etten-Towanda lineament. We suggest that the aeromagnetic high to the northwest of Watkins Glen has a similar origin and that a body of ultrabasic rock may lie near the surface.

We believe that the cited evidence suggests that the Seneca Lake - Elmira lineament zone has been tectonically active over a considerable span of geologic time. The evidence cited supports an hypothesis of basement controlled subsidence with the lineament acting as a hinge line for the subsidence. Precambrian basement is displaced downward an estimated 76 m (250 feet) to the east of the lineament zone. Stratigraphic units such as the Ordovician Trenton carbonates, Silurian Syracuse Formation "F" unit, rocks of the Devonian Deer Park and Onesquethaw Stages and the Devonian Tully Limestone thicken along a north trending trough to the east of the zone. We believe that movements occurred along near vertical faults similar to those noted by Harris (1978) for the bounding faults of the Rome Trough in central Pennsylvania. We speculate that the north trending axis of thickened sediments deposited during these periods may indicate a tectonically subdued branch of the Rome Trough. The postulated presence of ultrabasic intrusive rocks at the intersection of the Seneca Lake - Elmira lineament zone and the Watkins Glen-Taughannock lineament supports the premise of a deep seated fault(s) for the lineament zone.

We suggest that the lineament zone, because of the continual downwarping, produced a zone of inherent weaknesses in the deposited rocks, thereby localizing structures purportedly caused by the Alleghanian Orogeny. Thus, we believe that the lineament zone also marks the position of a regional tear fault or a ramp in the Silurian salt sequence. Evidence includes the thick block of Silurian Syracuse Formation "F" salt east of the lineament, the inferred tear faulting in the Syracuse Formation "D" unit along the zone, the documented thrust faulting normal to the inferred tear at Watkins Glen, NY, and deflections of the regional Alleghanian fold axes across the lineament zone. Inferred movement along the tear fault is left lateral. Gwinn (1964) cited similar types of data in the Allegheny Plateau of Pennsylvania and demonstrated that his examples were indicative of thin-skin tectonics.

We have attributed the thick Silurian Syracuse Formation "F" salt east of the lineament zone both to depositional mechanisms operating in the Silurian as well as tectonic thickening due to Alleghanian deformation. Additional evidence which we will point out in our discussion of the Endicott-Syracuse lineament zone and the West Danby Fault system will demonstrate that these three features owe their existence to Pre-Alleghanian tectonic activity, and that they were utilized as "avenues of least resistance" during the Alleghanian deformation.

The inferred thickening along the axis of Seneca Lake during the Late Cambrian-Early Ordovician and the graben-like structure observed in the Early Devonian and later rocks cannot be unequivocally attributed to either style of faulting, the block faulting of pre-Alleghany time nor the tear and thrust faulting associated with the orogeny. The graben-like structure we suspect, may be caused by the combined action of the two styles of tectonism, just as we cite dual causes for the thick Silurian units east of the lineament zone.

Painted Post - Blossburg Lineament Zone

The Painted Post - Blossburg lineament is a topographic lineament generally striking N20°W for approximately 74 km (46 miles) (figs. 2a, 6 and 7). Its expression is discontinuous, consisting of a portion of Meads Creek north of Coopers Plains, NY and stretches of the Tioga River between Erwins, NY and Blossburg, PA, where it passes from the south edge of the mapped area. Based on the 1:250,000 topographic maps, the lineament can be projected farther southward to the vicinity of Williamsport, PA. Because of its discontinuous nature and because of the variation in strike of the linear features along this projection, the alignment is best termed a lineament zone.

Because of the greath depth to rocks of the Salina Group, little is known of the structure below them. However, to the north of Keuka Lake and on strike with the lineament zone, a graben has been mapped on both the Precambrian (Rickard, 1973, pl. 18) and Ordovician Trenton surfaces (fig. 14). Isopachs of the Trenton carbonate rocks (fig. 13) parallel the lineament zone, suggesting the zone controlled facies and sedimentation patterns. The Upper Silurian Vernon "A" unit shows this lineament zone is parallel with and in close proximity to a facies change between mainly red shales to the east and interbedded red and green shales to the west (Rickard, 1969, pl. 4). The facies change may reflect a topographically lower area to the west in Vernon "A" time, paralleling the trough shown by the isopach of the Trenton carbonate rocks. The Upper Silurian Vernon "B" (fig. 15) and Syracuse "D-E" (fig. 16) units show no obvious relationship to the lineament zone. The Syracuse "F" salt (fig. 17) shows a marked change occurring between the Seneca Lake - Elmira and Painted Post - Blossburg lineaments. Isopachs of the Camillus Shale and Bertie Limestone show a salient parallel to and between both the Seneca Lake and Painted Post - Blossburg lineaments (Rickard, 1969, pl. 9). Rocks of the Devonian Onesquethaw Stage and isopachs of the Tully Limestone do not show anomalies along the lineament zone.

On the surface, the zone is marked by a change in strike of the Alleghanian folds axes, from northeast trends east of the zone, to east-northeast trends on the west side (fig. 20). The trends of the northeast joint set mapped in surface exposures also show changes which may be attributable to this lineament zone (Appendix B).

In Pennsylvania, the lineament zone parallels the west edge of an elongated aeromagnetic high (fig. 23). The aeromagnetic maximum is truncated to the north by a northeast trending minimum, which we believe is associated with the Cortland-Ithaca lineament. Interpretation of the digitally processed aeromagnetic data reveals offsets of deep magnetic basement (>4Km. depth) closely coincide with the second mapped lineament comprising this lineament zone north of the New York - Pennsylvania border (cf. fig. 7, this section and figs. E-13 & E-15, Appendix E).

The gravity expression of the Painted Post - Blossburg lineament (fig. 22) is not as obvious as is its aeromagnetic expression. However, the lineament zone does bound the west edge of a local gravity maximum which has a 9 milligal closure and the absolute highest values of gravity and aeromagnetic data coincide. The gravity closure is not represented in figure 31 because of the 10 milligal contour interval chosen for this presentation. Vozoff (1951) interpreted the local gravity maximum as representing a buried ultramafic intrusive; the new aeromagnetic data further reinforce his interpretation. A Jurassic-Cretaceous age is inferred for the buried intrusive based on other samples for ultrabasic rocks in the region (Zartmann and others, 1967).

We believe that the Painted Post - Blossburg lineament zone may be related to basement controlled faulting originating as early as the Early Ordovician and continuing in a subdued fashion for some time thereafter. Subdued tectonic activity along the lineament zone influenced control on sedimentation patterns and in some fashion, perhaps through weakening of the rocks along the zone by repeated minor tectonic adjustments or by the buttressing effect of different sediment facies or thicknesses across the zone, controlled the position of Alleghanian and later geologic structures.

Evidence supporting basement faulting includes offsets on deep magnetic basement and a graben structure mapped on the Precambrian and Ordovician Trenton carbonate rocks along the northward projection of the lineament zone. Isopachs and facies boundaries of Late Ordovician and Late Silurian rocks display parallelism to the lineament zone, suggesting the zone may have remained active as a depositional hinge line. The isopach data for the Upper Silurian Salina Group, however, cannot be interpreted unequivocally. The thickening seen in some of these units may be due to either subsidence during deposition of the units or Alleghanian tectonic thickening by thrust faulting. The migration of zones of maximum salt during deposition of the Salina Group (Rickard, 1969; Mesollela, 1978) supports the hinge line hypothesis, whereas the pervasiveness of thrust faulting within and above the salt units in the region, and the changes in the regional anticlinal axes along strike of the lineament, argue for thin-skinned deformation. Although we found no direct evidence for faulting along the lineament zone, we believe that the lineament zone represents a tear fault or ramp within the framework of thin-skinnned deformation.

We also suggest that the lineament, besides being basement controlled, is also a profound weakness in the crust. The combined gravity and aeromagnetic data support the hypothesis of a buried ultrabasic intrusive along the lineament, inferring a mantle source. We speculate that this postulated intrusive is localized by the intersection of the Painted Post - Blossburg lineament zone and the southwestward projection of the Cortland - Ithaca lineament. We, like Parrish (1978), believe that these intrusives occur at intersections of deep-seated fault zones; here the intensely crushed rocks will provide the path of least resistance for the intrusive.

Endicott-Syracuse Lineament Zone

The Endicott-Syracuse lineament is delineated primarily by a subparallel alignment of water bodies striking approximately N23°W (figs. 2a, 6 and 7). It is expressed discontinuously in the landscape from Skaneateles Lake on the north, southward along Factory Brook, and portions of the Tioughnioga, Chenango and Susquehanna Rivers in New York and along Martins and Partners Creeks in Pennsylvania, for approximately 120 km (75 miles). A conspicuous drainage deflection of the Susquehanna River defines a portion of this lineament (figs. 2a, 6 and 7). Because of the lineament's discontinuous nature, it is best termed a lineament zone.

Numerous units both above and below the Silurian Salina salt beds show changes along this zone. Rickard's map of the Middle Ordovician Black River carbonate rocks (Rickard, 1973, pl. 7), shows isopachs parallel to the lineament zone and an inferred unconformity with the loss of the uppermost Black River rocks just east of and subparallel to the zone. Isopachs of Upper Ordovician Trenton carbonate rocks parallel the zone (fig. 13), with thickness increasing westward. The lineament zone itself is marked by a westward increase in isopach gradients.

Isopachs of the "D & E" units (fig. 16) of the Upper Silurian, Upper Syracuse Formation show parallelism to the lineament zone in its northern parts.

Isopachs of the "F" unit (fig. 17) of the Upper Syracuse Formation show a rapid thinning in the salt beds eastward across the lineament zone, and a change from mainly chemical precipitates on the west to clastic sediments east of this zone. This westward increase in the rate of thickening of the carbonate rocks is matched by an eastward increase in the thickening gradient of clastic rocks of equivalent age (Rickard, 1973).

Isopachs of the Camillus Shale and Bertie Limestone (Rickard, 1969, pl. 9) show small inflections across the lineament zone; the units are slightly thicker to the east.

The Tully Limestone of Middle Devonian age is the youngest stratigraphic unit which appears to show a control exerted by the lineament zone. Wright (1973) (fig. 19) shows a conspicuous thinning of the Tully east of the lineament zone. Heckel (1973) considers the Tully Limestone an anomalous unit of relatively pure limestone in the otherwise predominantly clastic Middle and Upper Devonian sequence. He proposes a structurally controlled downwarp acting as a sedimentational trap striking approximately north-northeast which restricted the spread of clastic sediments being shed westward from the prograding Catskill Delta. Although the strike of the trap does not agree completely with our feature, it is in the approximate position of the lineament zone.

Many of the east-trending fold axes of Alleghanian structures in New York and conterminuous portions of Pennsylvania (fig. 20) die out within close proximity to the lineament zone. This includes the relatively low amplitude folds in New York as well as the higher amplitude folds in northeastern Pennsylvania. Engelder and Engelder (1977) propose a left-lateral shear zone in New York coincident with the lineament zone based on fossil distortions in the Devonian rocks exposed at the surface.

To the east of the lineament zone, the Susquehanna River generally flows to the southwest (fig. 2a). Within the region of the lineament zone, the river abruptly changes course to south-southeast, west and north-northwest before finally resuming its southeasterly course. These deflections (SD, fig. 2a) cause the stream to follow a 55 km (34 mile) course compared to 15 km (9 mile) course were it able to continue its regional southwesterly trend. Coates (pers. comm. to H. Pohn, 1978) believes that the drainage reversal is due to glacial damming of the Susquehanna drainage during the Pleistocene. However, we believe that the sharp angularity of the overall pattern of deflections reflects some north-northwest oriented structural discontinuity along the lineament zone.

Seismic reflection surveys across the lineament zone are unavailable. However, those data that do exist suggest some pronounced changes in depth to basement within the general vicinity of the lineament zone. Seismic two-way time to basement at North Spencer, NY, the closest point to the western boundary of the lineament zone (55 km west) is 1.7 seconds. At Greene, NY, which is 68 km nearly due east and on the eastern boundary of the lineament zone, seismic two-way time to basement is 1.40 seconds. Two-way time to basement gradually decreases to 1.35 seconds along a seismic line extending 58 km (36 miles) east of Greene, NY. It has been assumed that basement structure contours are oriented generally east-west in the New York portion of the study area. If this assumption is correct, the major change in time to basement occurs either because of a change in the structural dip of the basement or because of a basement fault between North Spencer and Greene, NY. Rickard's map (1973, pl. 18) of structure contours on the crystalline basement generally shows this shallowing of basement to the east with an inflection in the vicinity of the lineament zone. Although tenuous as a single argument for basement involvement, it is reinforced by the stratigraphic data presented earlier and by other geophysical data.

The aeromagnetic map (fig. 23) shows a series of aligned highs along the trend of the lineament zone. Interpretation of the digitally processed aeromagnetic data shows that magnetic basement is generally at depths greater than 4 km west of the lineament zone (figs. E-13 & E-17, Appendix E). The gravity map (fig. 22) shows a series relatively low amplitude (<6 milligal) gravity minimum and maxima along the lineament, suggesting a basement discontinuity.

Pencil siltstones have been found at four localities in the lineament zone (Appendix D, fig. D-2). The long axes of the pencil siltstones trend within a few degrees of the strike of the lineament zone. The prevailing joint directions also shift subtly in the vicinity of the lineament zone.

In summary, we believe the Endicott-Syracuse lineament zone is related to a basement disruption as well as a zone of Alleghanian tear faulting. Its surface expression, besides the stream alignments, is further accentuated by anomalous deflections in the course of the Susquehanna River within the lineament zone and supports an hypothesis of underlying tectonic control. The changes in joint patterns associated with the lineament zone further reinforces this hypothesis. Sedimentation data suggests the zone has acted as a depositional hinge line, perhaps fault controlled, from the Middle Ordovician to at least the Middle Devonian. Seismic reflection surveys indicate a marked change in depth to basement may occur within a region that includes the lineament zone. Magnetic basement is generally deeper to the west of the zone.

We postulated that the depositional pattern of the Silurian salt sequence, particularly the Salina "F" salt, has been controlled by this basement hinge line. Evidence also suggests that the lineament zone acted as a left lateral tear fault system (Engelder and Engelder, 1977) during the Alleghanian orogeny. The setting here appears analogous to that cited by both Gwinn (1964) and Rodgers (1964), who showed that presence or absence of incompetent beds determined the style of tectonic deformation during the Alleghanian Orogeny. The thick incompetent salts to the west of the lineament zone would favor development of thin-skinned folds, whereas the thin salts to the east and the concomitant increase in more competent clastics, would be less conducive to folding east of the zone. The result might well manifest itself as a tear fault, corresponding to the lineament zone. Engelder and Engelder (1977) offer independent support of this hypothesis, as they propose a region of left-lateral shear based on fossil distortion that corresponds both in position and strike to the lineament zone.

Van Etten-Candor Lineament

The Van Etten-Candor lineament is expressed as a continuous line of stream valleys consisting of portions of Dean and Catatonk Creeks, between Van Etten and Candor, N. Y. (Figs 2a, 6 and 7). The lineament is 19 km (12 miles) long and strikes N75°E, approximately parallel to the anticlinal axes of the Alleghenian fold structures. During the Pleistocene epoch the valley acted as a major "through valley" (Williams and others, 1909).

A detailed areal study of deep well data is not possible because these data are too sparse. However, maps derived from analysis of purchased proprietary seismic reflection surveys (Appendix F) show that time contours on reflecting horizons below the salt (Theresa Dolomite, Trenton Limestone and Lockport Dolomite) essentially parallel the lineament and the inferred regional strike of the basement. A change in dip, increasing southward, may occur on the Theresa and Trenton horizons, but sufficient control is lacking to prove this point conclusively. Strong inflections of time contours do occur along a north-south line to the south of Van Etten, but these are most likely related to the Van Etten-Towanda lineament discussed earlier.

The top of the Onondaga Limestone, the first readily recognizable seismic reflective horizon above the salt, shows a complex set of faults lying directly along the lineament. The pattern of faulting suggests a downdropped graben structure along the axial trend of the Van Etten anticline, a structure reminiscent of the Woodhull anticline in Steuben County, NY to the southwest of this area (Frey, 1973), and those in Pennsylvania discussed by Gwinn (1964). The pattern, observed in numerous maps covering better known portions of the Allegheny Plateau of New York, Pennsylvania and West Virginia, is part of a thrust-backthrust style of faulting, a conspicuous element of thin-skin tectonics. As might be expected, the master decollement within the area lies within the Silurian Salina Group salt (see fig. F-1, Appendix F). The Tully horizon shows little direct evidence for faulting, sugsing southward, may occur on the Theresa and Trenton horizons, but sufficient control is lacking to prove this point conclusively. Strong inflections of time contours do occur along a north-south line to the south of Van Etten, but these are most likely related to the Van Etten-Towanda lineament discussed earlier.

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Aeromagnetic data (fig. 23) depict a low amplitude elongate minimum lying along the lineament. Interpretation of the digitally processed aeromagnetic data (Appendix E) reveals downfaulting or increased dips on the magnetic basement to the south of the lineament. The increase in dips on top of the Theresa and Trenton units mentioned earlier in this section favors the existence of a basement hinge line along the lineament (see Appendix F).

In summary, the Van Etten-Candor lineament appears to be related to thrust faulting within and above the salt horizons. The thrust faulting may also be localized due to the presence of a basement hinge line below the salt, as is indicated by possible increases in dip of the subsalt horizons and in magnetic basement.

Van Etten-Odessa Lineament

The Van Etten-Odessa lineament is expressed in the topography as a nearly continuous alignment of the valleys of Cayuta and Lehigh Creeks, which trend approximately N50°W, from Van Etten on the southeast to Odessa, NY on the northwest, a distance of 24 km (15 miles) (figs. 2a, 8, and 9). During the Pleistocene epoch, the valley served as a primary "through valley" (Williams and others, 1909).

Deep well and surface data are sparse, so that structure contours cannot be projected across the lineament with accuracy sufficient to ascertain the existence of a structurally disturbed zone. However, seismic reflection surveys show several interesting features. Contours of two-way travel time on the Cambrian Theresa Dolomite generally strike northwest along the lineament, a marked change from their general easterly strike east of Van Etten, NY (fig. F-13, Appendix F). A northwest trending graben is located about 3.2 km (2 miles) southwest of Van Etten. Several small folds with axes trending northwest-southeast are located along and south of this graben. Structural trends are less apparent to the north of the fault; the low gradients northwest of Van Etten appear to be a reflection of the Van Etten dome. A strong northwesterly pattern of minor folds and faults is also found on the overlying Trenton and Lockport units (figs. F-12 & F-11 respectively, Appendix F) and a small dome is present on both units in the position of the graben on the Theresa horizon. Reflecting horizons above the Salina salt show totally different patterns. Faults observed on the Onondaga Limestone (fig. F-10, Appendix F) parallel the trend of the Alleghanian folds. Several synclinal features north and west of Van Etten appear to have local maxima or "saddles" in proximity to the lineament for both the Tully and Onondaga Limestones (figs. F-9 and F-10, Appendix F).

The gravity map shows no linear trends which might be associated with the Van Etten-Odessa lineament (fig. 22). Interpretation of digitally processed aeromagnetic data (Appendix E) suggests that the southwest end of the lineament is coincident with the southwest flank of the basement-controlled Van Etten dome.

In summary, the Van Etten-Odessa lineament has been mapped in the subsurface almost exclusively on the basis of seismic reflection surveys. It's origin is enigmatic, because it does not appear to correlate directly with most subsurface structures. Faults with the same trend can be seen in horizons below the salt approximately 3.2 km (2 miles) southwest of the lineament. Faulting is not apparent in the beds above the salt sequence, although some synclines appear to lose closure along the lineament.

A possible origin for the lineament involves the propogation of a basement fracture system into the Devonian rocks prior to the Alleghanian orogeny. We hypothesize that the fractured rocks comprising this zone may have been transported laterally northward to their present position during the Alleghanian orogeny with subsequent glacial erosion enchancing the feature. If this model is correct, we may have some estimate of the amount of lateral (north-south) foreshortening in the immediate area, approximately 3.2 km.The time of the faulting or folding in the units below the Silurian salt sequence is presently unknown. Similar deformational features present from Cambrian through Middle Silurian time suggest a post Silurian deformation. Based on the directions and styles of known orogenic movements for the area and the rocks affected, we believe the units below the salt also may have been affected by Alleghanian deformation.

West Danby Fault System

The West Danby fault system (fig. 21), associated with the Danby (Alpine) anticline, does not appear as a lineament on the images, but rather was found as a result of field mapping during this program. We believe that the fault system does not show up as a lineament on the Landsat images because the area has been subjected to glacial scour. Few significant valleys are apparent anywhere in the area. The feature is important inasmuch as the Danby anticline is the northermost of the large Alleghanian folds and marks the northern boundary of the thick Silurian Salina "F" unit rocks (fig. 17). Fettke (1954) recognized a single fault in the subsurface. Our studies have expanded it into a fault system which intersects the surface.

At the surface, the fault system is recognized by anomalously steep bedding dips of as much as 19° in an area where the maximum dips normally range from one to three degrees. The inferred faults, two thrusts northward and one antithetic, appear to be at the crest of the Danby (Alpine) anticline, and are similiar to those described elsewhere in the Plateau (Gwinn, 1964; Frey, 1973). At the surface the faults strike nearly E-W in a zone that varies from 2.5 to 4 km (1.5 to 2.5 miles) wide and extends for a distance of 24 km (15 miles) from southwest of the village of Catharine, NY eastward to the longitude of the village of West Danby.

An outcrop of pencil siltstones 0.5 km east of Catharine marks the proposed westernmost end of the antithetic fault. The long axes of the pencils trend N85W, nearly parallel to the fault system. The strike of the two regional joint sets changes subtly across the fault zone.

Subsurface data for the West Danby faults are relatively sparse in the published literature. As mentioned earlier, the Silurian Salina "F" unit becomes markedly thicker south of the fault (fig. 17). Structure contours map on the Oriskany Sandstone, Fettke (1954), indicate a nearly east-west trending fault downdropped to the south about 121 m (500 feet). He also indicates that the sandstone is absent along the anticline in this region. The Middle Devonian Tully Limestone appears to be broken by the same fault (deWitt, unpub. map). Bradley and Pepper (1941) indicate steep structure contour gradients on the Upper Devonian Rhinestreet Shale exposed at the surface along the fault zone, but found no clearly recognizable fault. More recent well data indicate that Fettke's data were too limited and that the structure is an anticline with a downfaulted crest (Beardsley, Columbia Gas Corp., pers. comm., 1979), similar to the Woodhull anticline in Steuben County NY (Frey, 1973; Appendix F, fig. F-1). Proprietary seismic data (Beardsley, Columbia Gas Corp., pers. comm., 1980) indicates that the majority of the deformation occurs within and above the Silurian Salina Group; hence the anticline is a thin-skinned fold. However, in a regional north-south oriented seismic reflection survey, the south dip of the basement and subsalt horizons increases at the Danby anticline (Beardsley, Columbia Gas Corp., person. comm., 1980) suggesting a basement downwarp or growth fault intermittently active up to and perhaps through the time of deposition of the Salina Group. The digitally processed aeromagnetic data show an east-west alignment of magnetic basement disruptions in the approximate position of the fault system, although the alignment may be the result of the east-west oriented flightlines used in gathering this data (cf. fig. 21 this section and figs. E-13 and E-17, Appendix E).

We believe the West Danby fault system is an Alleghanian structure, but its position is the product of pre-Alleghanian deformation which occurred primarily as a reactivated basement hingeline or fault. The hingeline hypothesis is supported by seismic data which show basement increasing in dip to the south at the fault system, and stratigraphic data which show the Salina "F" salt markedly thickened south of the fault system. Movement must have been oscillatory with time, because the Oriskany Sandstone is absent along the trend of the faults. The southeastward migration of maximum salt deposition during Salina time also reinforce a structurally controlled depositional environment (cf. figs. 15-17). The Danby anticline also exhibits typical thin-skinned deformation characteristic of Alleghanian deformation elsewhere on the Plateau. The relatively high structural amplitude (183 m or 600 feet) of the fold in comparison to neighboring folds 32 km (20 miles) to the north or south, the conspicuously thinner salt units to the north and the faulting along the crest of the Danby anticline are analogous to the structural setting of the Burning Springs anticline in the Plateau of West Virginia. Rodgers (1964) cites the same type of evidence for the Burning Springs anticline and suggests that the lack of incompetent salt beds to the west caused the master decollement to splay upward, transforming primarily horizontal displacements along the decollement into vertical displacements responsible for a structural amplitude unmatched by any fold within 112 km (70 miles) (Rodgers, 1964). We concur with his interpretation and believe the analog holds true for the West Danby fault system and the Danby anticline.

SUMMARY and CONCLUSIONS

We made a study of the relationship between lineaments observed on Landsat satellite images and the geologic framework of a portion of the Allegheny Plateau of south-central New York and northern Pennsylvania. The area is underlain by a relatively thick sequence of salt and other evaporites in the Silurian Salina Group and is a potential site for deep-storage of solid nuclear waste. A combination of remote sensing techniques, detailed geologic mapping and geophysical investigations were applied to the problem. Because of the premature termination of the Department of Energy contract, only a portion of the total work was completed.

The completed portion of the project included 1) digital contrast enhancement of several Landsat multispectral scanner (MSS) images, 2) analysis of lineament patterns from a Landsat MSS-7 mosaic, 3) field mapping of bedrock joint patterns, 4) compilation and analysis of surface and subsurface structure and isopach maps, 5) collection and digital analysis of aeromagnetic data for southern New York, 6) compilation and qualitative analysis of aeromagnetic and gravity data for much of New York and Pennsylvania, and 7) analysis of seismic reflection survey lines for selected portions of New York and Pennsylvania.

We identified eight major lineaments or lineament zones and studied them in detail. They typically represent linear alignments of the most conspicuous or prominent physiographic features observable on the Landsat images. Lineament zones are composed of a sequence of parallel to subparallel aligned lineaments, whereas lineaments are essentially nearly continuous single linear features.

The Cortland-Ithaca, Watkins Glen-Taughannock, Seneca Lake-Elmira, Painted Post-Blossburg and Endicott-Syracuse lineament zones were defined from our lineament map. The most conspicuous lineaments include Corning-Bath, Van Etten-Towanda, Van Etten-Candor and Van Etten-Odessa lineaments. In addition, a major fault system--the West Danby fault zone--was further defined by geologic and geophysical investigations during our study; the fault zone was not recognizable on satellite images. The lineaments and lineament zones were categorized by their azimuthal trends. Those with a northerly orientation (e.g. Van Etten-Towanda, Seneca Lake-Elmira, Painted Post-Blossburg and Endicott-Syracuse) are most common. Northeast-trending lineaments (e.g. Cortland-Ithaca and Watkins Glen-Taughannock) also are common. The Corning-Bath and Van Etten-Odessa lineaments have a northwesterly orientation and the Van Etten-Candor lineament is the sole representative of the east-west direction. The West Danby fault system also trends east-west.

All the lineaments or lineament zones studied appear to be related, in one fashion or another, to structural disturbances, because changes in the structural attitude of beds or thickness of rocks commonly occur along their extent. The changes in many instances occur on multiple stratigraphic horizons and in a manner suggestive of several different styles of tectonism, leading to the conclusion that the lineaments and lineament zones have been periodically reactivated during the Paleozoic and Mesozoic ? Eras. Aeromagnetic data commonly show a parallel alignment of contours juxtaposed or on line with lineaments and lineament zones, suggesting that these physiographic alignments owe their origin to features within the crystalline basement.

Pre-Alleghanian faulting and depositional patterns show that the study area was affected by basement-controlled adjustments along and in the same direction as most of the lineaments and lineament zones. Actual displacements cannot be proven for all of the lineaments or lineament zones, but changes in dip of the rocks across these features suggest either basement hingelines or small displacement faulting which cannot be resolved by the present data. We believe these movements are primarily vertical. These displacements occurred in at least Middle-Late Ordovician, Middle-Late Silurian and the Early-Middle Devonian times. The major northeast trending lineament zones (Cortland-Ithaca and Watkins Glen-Taughannock) correspond in orientation and lie along the northeastward projection of the Rome Trough, a postulated Paleozoic aulacogen. Prior workers had extended the trough northeastward only to north-central Pennsylvania. We postulate that the lineament zones are an expression of the Rome Trough and it thus extends into New York. However, movements were more subdued than those which occurred farther southward in Pennsylvania and West Virginia. Ordovician sedimentation patterns and faulting suggest that the north-trending lineaments (Painted Post-Blossburg, Seneca Lake-Elmira, Van Etten-Towanda and Endicott-Syracuse) also may be related to the northeasterly trending lineaments, implying that the main part of the trough may have died out in a series of faults of decreasing magnitude trending in the north and northeast directions.

The easterly trending features (Van Etten-Candor lineament and the West Danby fault system) appear to be related to sedimentational hinge lines, with stratigraphic units below the salt beds increasing in dip southward of the features into the Appalachian Basin. The northwesterly trending features have the least supporting evidence for their relation to structure, however, limited evidence suggests that the Corning-Bath lineament is a major gravity discontinuity and appears as a hinge line or sedimentation trap affecting facies in the Ordovician and Devonian respectively. The Van Etten-Odessa lineament is paralleled by a series of faults which exist only below the Silurian salt units and which are located about 3 km south of the lineament.

Thrust- and tear-faults are the dominant features of thin-skinned tectonism associated with the Alleghanian orogeny. The faults appear to be localized along those lineaments and lineament zones which have preferred directions with respect to the northerly directed compressional forces of the orogeny. Northerly trending lineaments (Painted Post-Blossburg, Seneca Lake-Elmira, Van Etten-Towanda, and Endicott-Syracuse) developed above tear faults or ramps, whereas the single documented easterly trending lineament (Van Etten-Candor) is associated with thrust faulting. The West Danby fault system also is a series of forward and antithetic thrusts and defines the northern extent of a relatively thick

Silurian "F" salt unit. Subsurface and outcrop data were insufficient to ascertain the relationship of the northeasterly and northwesterly trending linear features to Alleghanian structures.

Ultrabasic intrusives of Jurassic-Cretaceous age appear to be localized along or at the intersections of some of the lineaments or lineament zones, attesting to the deep crustal origin of these linear features.

The rectilinear nature of the thick Upper Silurian Syracuse Formation "F" salt (fig. 17) is more than likely a product of more than one structural style of deformation. The salt "block" is bound on the west by the Seneca Lake-Elmira lineament zone, on the east, by the Endicott Syracuse lineament zone and on the north, by the West Danby fault system.

On one hand, the general shape of the block and its relation to the Alleghanian folds begs for a thrust sheet interpretation for the block, with the east and west bounding lineament zones acting as tear faults and the northward displacement being taken up along splay faults of the West Danby fault system. We have cited evidence which corraborates this thesis. Two lineaments within the rectilinear block also display thrust or tear fault attributes. Thus, where on a megascopic scale only one large thrust sheet is recognized, more detailed inspection reveals that the block probably consists of many smaller blocks bounded by their own thrusts and tears.

On the other hand, these same lineaments and fault zones are associated with basement disruptions and isopach patterns that suggest that at least part of the rectilinear form of the salt block is due to control of the depositional basin by faulting and downwarping prior to the Alleghanian Orogeny.

We believe that the salt block existed in more or less its present form prior to the Alleghanian Orogeny. Tear and thrust faulting took advantage of the more fractured rocks present along the hinge lines and the differences in thickness of the incompetent rocks on either side of these lines to form tear, ramp and thrust faults along these pre-existing lines of weakness. Where the incompetent rocks become thinner, thin skin folding becomes less apparent or dies out.

RECOMMENDATIONS

Although this study is incomplete because of the premature termination of the contract, the following statements may be made.

We believe the data examined show the study area to be structurally complex, having undergone several periods of deformation. The stratigraphic units proposed as potential storage beds for disposal of nuclear wastes appear to be affected by both Pre-Alleghanian extensional (?) deformation as well as Alleghanian compressional and shear tectonism. Although it appears from the published literature that compressional and shear faults in evaporite beds may be self-healing, the postulated extensional tectonism may have adversely affected the integrity of these beds. This point requires further investigation.

The lineaments studied appear to break up the study area into a series of polygonal blocks, suggesting that areas within individual blocks, if large enough, may be suitable for waste disposal. However, it should be kept in mind that only major lineaments were examined, and that many smaller linear features lying within the individual blocks also may have affected the structural integrity of the rocks. Further studies should be made to determine the integrity of these areas should the project be pursued again sometime in the future.

Figure

1 Index Map to study area.
Hachured area - Regional study area; Cross-hachured area - Local study area.

2a Uncontrolled Landsat MSS-7 photomosaic of the study area and surrounding regions.
Key to symbols: AD - Adirondack Dome; B - Bath, NY; Bg - Bloomsburg, PA; Bl - Blossburg, PA; Ca - Cayuga Lake; Cr - Corning, NY; Ct - Cortland, NY; El - Elmira, NY; En - Endicott, NY; It - Ithaca, NY; K - Keuka Lake; L - Lackawanna Syncline; N - Nittany Anticlinorium; S - Susquehanna River; SD - anomalous deflection of the Susquehanna River--the symbol is situated on an upland which impedes the southwesterly flow of the river; Se - Seneca Lake; Sk - Skaneateles Lake; Sy - Syracuse, NY; T - Towanda, PA; W - Williamsport, PA.

2b Index to Landsat scene ID's and their dates used in the photomosaic.

3 Computer enhanced MSS-7 image for the eastern portion of Landsat scene 1459-15221.
Key to symbols: Bl - Blossburg, PA; Ca - Cayuga Lake; Ch - Chenango River; Cn - Candor, NY; Cr - Corning, NY; El - Elmira, NY; En - Endicott, NY; It - Ithaca, NY; Od - Odessa, NY; S - Susquehanna River; Se - Seneca Lake; Sp - Spencer, NY; T - Towanda, PA; VE - Van Etten, NY; WG - Watkins Glen, NY.

4 Lineament map derived from the computer enhanced eastern half frame of Landsat scene 1459-15221 using Procedure I. Heavy solid lines - readily apparent lineaments; light solid lines - less conspicuous lineaments.

5 Lineament map derived from the computer enhanced eastern half-frame of Landsat scene 1459-15221 using Procedure II. Heavy solid lines - readily apparent lineaments; light solid lines - less conspicuous lineaments.

6 Lineament map derived from the Landsat MSS-7 photomosaic of figure 2a using Procedure I. Heavy solid lines - readily apparent lineaments; light solid lines - less conspicuous lineaments. Outlines of the major Finger Lakes shown for location purposes.

7 Location map of selected lineaments described in this paper. Key to lineaments and lineament zones: 1 - Cortland - Ithaca; 2- Watkins Glen - Taughannock; 3 -Corning - Bath; 4 - Van Etten - Towanda; 5 - Seneca Lake - Elmira; 6 - Painted Post - Blossburg; 7 - Endicott - Syracuse; 8 - Van Etten - Candor; 9 - Van Etten - Odessa.

8 Analysis of lineaments from the eastern half of Landsat scene 1459 - 15221 using Procedure I for relationship to topography and culture.

20 Comparison of selected lineaments with map of anticlinal axes. Compiled from Wedel (1932), Fettke (1954) and Cate (1961). Queries indicate uncertain correlations. Lineament annotation same as fig. 7.

21 Comparison of selected lineaments with structural formline map for the study area based on the top of the Lower Devonian Pipe Creek Shale. Refer to figure 10 for stratigraphic relationships. Sources of data are listed; where unit names are not accepted by the Committee for Statigraphic Nomenclature, original describing authors are also listed. Horizons used in the compilation; A1 - base of the Rhinestreet Shale (Bradely and Pepper, 1941); A2 - base of the Canaseraga Sandstone (Dunkirk Sandstone of Bradely and Pepper, 1941); B - base of the Moreland Shale of Humes (1960); C - top of the Roricks Glen Member of Nugent (1960), Rhinestreet Shale; D - top of the Second Conglomerate equivalent of Nugent (1960), Pipe Creek Shale; E - top of the Pipe Creek Shale (Woodrow, 1968); F - top of the Dunkirk Sandstone of Bradely and Pepper (1941) (Woodrow, 1968); G - top of the Corning Member of Sutton (1963), Gardeau Formation (Woodrow, 1968); H - this study, field mapping of surface units. Lineament annotation same as fig. 7. Contour elevations x100 feet.

22 Comparison of selected lineaments with a Simple Bouger gravity map for portions of New York and Pennsylvania. New York data compiled from Diment and Revetta (1971), Simmons and Diment (1973), Diment and others (1973), Uraban and others (1973). Pennsylvania data compiled from Muller and others (1979; unpublished data). Lineament symbols same as fig. 7. Key to additional symbols: cl - Clarendon - Linden fault system; k - Kane Gravity High; l - Lawrenceville Gravity High, s - Scranton Gravity High, t - trough-shaped gravity minimum, w - Waverly Gravity Low.

23 Comparison of selected lineaments with the aeromagnetic map for portions of New York and Pennsylvania. New York data compiled from U.S. Geological Survey (1975, 1977, 1979). Data for Pennsylvania from U.S. Geological Survey (1978). Lineament symbols same as fig. 7. Key to additional symbols: d - Danby aeromagnetic maximum; m - Myers aeromagnetic maximum, v - Van Etten aeromagnetic maximum.

24 Comparison of selected lineaments with two-way times to basement for the study area. Lineament symbols same as fig. 7.

REFERENCES

Bradley, W. H., and Pepper, J. F., 1941, Structure and gas possibilities of the Oriskany sandstone in Steuben, Yates, and parts of the adjacent counties; U.S. Geological Survey Bulletin 899A, 68 p.

Brunton, G. D., Laughon, R. B., McClain, W. C., 1978, Screening specifications for bedded salt, Salina Basin, New York and Ohio; U.S. Department of Energy, Office of Waste Isolation, TM-54, 11 p.

Cate, A. S., 1961, Stratigraphic studies of the Silurian rocks of Pennsylvania - Part 1, Stratigraphic cross sections of Lower Devonian and Silurian rocks in western Pennsylvania and adjacent areas; Pennsylvania Geological Survey, 4th series, Special Bulletin 10, 9 p.

Clayton, K.M., 1965, Glacial erosion in the Finger Lakes region (New York, USA); Zietschrift fur Geomorphologie, v. 9, p. 50-62.

Cloos, Ernst, 1946, Lineation; Geological Society of America Memoir 18, 122 p.

Cooper, B. N., 1961, Grand Appalachian field excursion; Virginia Polytechnic Institute, Engineering Extension Series, Geological Guidebook 1, 187 p.

Diment, W. H., Urban, T. C., and Revetta, F. A., 1972, Some geophysical anomalies in the eastern United States, in Nature of the Solid Earth (Robertson, E. ed); McGraw-Hill, New York, p. 544-572.

Diment, W. H., Revetta, F. A., Porter, C. O. and Simmons, G., 1973, Simple Bouger anomaly map of east-central New York; New York State Museum and Science Service, Geological Survey, Map and Chart Series No. 176, scale 1:250,000.

Diment, W. H., Muller, O. H., and Lavin, P. M., 1980, Basement tectonics of New York and Pennsylvania as revealed by gravity and magnetic studies; in The Caledonides in the U.S.A. (Wones, D. R., ed), Proceedings of 1979 Project 27 Meeting, Department of Geological Sciences, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, p. 221-227.

Engelder, T., and Engelder, R., 1977, Fossil distortion and decollement tectonics of the Appalachian Plateau; Geology, v. 5, p. 457-460.

Engelder, T., and Geiser, P., 1979, The relationship between pencil cleavage and lateral shortening within the Devonian section of the Appalachian Plateau, New York; Geology, v. 7, p. 460-464.

Fettke, C. R., 1933, Subsurface Devonian and Silurian sections across northern Pennsylvania and southern New York; Geological Society of America Bulletin, v. 44, p. 601-659.

_______________ 1954, Structure-contour maps of the Plateau region of north-central and western Pennsylvania; Pennsylvania Geological Survey Bulletin G27, 50 p.

Finn, F. H., 1949, Geology and occurrence of natural gas in Oriskany sandstone in Pennsylvania and New York; American Association of Petroleum Geologists Bulletin, v. 33, p. 303-335.

Frey, M. G., 1973, Influence of Salina salt on Structure in New York-Pennsylvania part of the Appalachian Plateau; American Association of Petroleum Geologists Bulletin, v. 57, p. 1027-1037.

Gold, D. P., 1977, A study of the Tyrone-Mt. Union lineament by remote sensing techniques and field methods; Final Report, Contract NAS5-22822, NASA-Goddard Space Flight Center, Greenbelt, Maryland, 59 p.

Gwinn, V. E., 1964, Thin-skinned tectonics in the Plateau and northwestern Valley and Ridge Provinces of the Central Appalachians; Geological Society of America Bulletin, v. 75, p. 863-900.

Hall, James, 1839, Third Annual Report, Fourth Geological District of the State of New York; New York Geological Survey Annual Report 3, p. 287-339.

_______________ 1843, Geology of New York, Part IV, comprising the survey of the fourth geological district, 683 p.

Harris, L. D., 1970, Details of thin-skinned tectonics in parts of Valley and Ridge and Cumberland Plateau Provinces of the Southern Appalachians, in Studies of Appalachian Geology (Fisher, G. W., Pettijohn, F. J., Reed, J. C., Jr., and Weaver, K. N., eds.); Wiley and Sons, p. 161-173.

_______________ 1978, The eastern interior aulacogen and its relation to Devonian shale-gas production; Proceedings 2nd Eastern Gas Shales Symposium, Morgantown Energy Technology Center SP-78/6, p. 55-72.

Heckel, P. H., 1973, Nature, origin, and significance of the Tully Limestone; Geological Society of America Special Paper 138, 244 p.

Humes, E. C., Jr., 1960, The geology of portions of the Watkins Glen and Ithaca 15 minute quadrangles; unpublished Master of Science thesis, University of Rochester, 55 p.

Hunter, P. M., and Parizek, R. R., 1979, A structurally disturbed zone in central Pennsylvania: Surface expression of a domain boundary?; in Proceedings 2nd International Conference on Basement Tectonics (Podwysocki, M. H., and Earle, J. L., eds.), Basement Tectonics Committee, Denver, Colorado, p. 111-121.

Isachsen, Y. W., 1976, Fracture Analysis of New York state using multi-stage remote sensor data and ground study; Possible application to plate tectonic modeling; in Proceedings 1st International Conference on New Basement Tectonics (Hodgson, R. A., Gay, S. P., Jr., and Benjamins, J. Y., eds.), Utah Geological Association Publication No. 5, p. 200-217.

Jacoby, C. H., and Dellwig, L. F., 1974, Appalachian foreland thrusting in Salina salt, Watkins Glen, New York, in 4th Symposium on Salt (Coogan, A. H., ed.); Northern Ohio Geological Society, p. 267-275.

Kindle, E. M., 1904, A series of gentle folds on the border of the Appalachian system; Journal of Geology, v. 12, p. 281-289.

Kowalik, W. S., and Gold, D. P., 1976, The use of Landsat-1 imagery in mapping lineaments in Pennsylvania, in Proceedings of the 1st International Conference on the New Basement Tectonics (Hodgson, R. A., Gay, S. P., Jr., and Benjamins, J. Y., eds.); Utah Geological Association Publication 5, p. 236-249.

Landes, K. K., 1945, The Salina and Bass Island rocks in the Michigan Basin; U.S. Geological Survey, Oil and Gas Investigation Map 40.

Martens, J. H. C., 1924, Igneous rocks of Ithaca, New York and vicinity; Geological Society of America Bulletin, v. 35, p. 305-320.

Mesolella, K. J., 1978, Paleogeography of some Silurian and Devonian reef trends, Central Appalachian Basin; American Association of Petroleum Geologists Bulletin, v. 62, p. 1607-1644.

Muller, O. H., Ackerman, H. D., Diment, W. H., Lavin, P. M., LeClair, L. D., Revetta, F. A., Sumner, J. R., Trembley, J. A., and Urban, T. C., 1979, A preliminary gravity map of Pennsylvania; Geological Society of America, Abstracts with Programs, v. 11, p. 46.

McCann, T. P., Privrasky, N. C., Stead, F. L., and Wilson, J. E., 1968, Possibilities for disposal of industrial wastes in subsurface rocks on north flank of Appalachian Basin in New York, in Subsurface Disposal in Geologic Basins - A Study of Reservoir Strata (Galley, J. E., ed.); American Association of Petroleum Geologists Memoir 10, p. 43-92.

Nugent, R. C., 1960, The geology of the Elmira, Waverly, and Owego quadrangles, New York; unpulished Master of Science thesis, University of Rochester, 96 p.

O'Leary, D. W., Friedman, J. D., and Pohn, H. A., 1976, Lineament, linear, lineation -- some proposed new standards for old terms; Geological Society of America, v. 87, p. 1463-1469.

Oliver, W. A., Jr., deWitt, W., Jr., Dennison, J. M., Hoskins, D. M., and Huddle, J. W., 1971, Isopach and lithofacies maps of the Devonian in the Appalachian Basin; Pennsylvania Geological Survey, Progress Report 182, 7 plates.

Parrish, J. B., 1978, The relationship of geophysical and remote sensing lineaments to regional structure and kimberlite intrusions in the Appalachian Plateau of Pennsylvania; unpublished Master of Science thesis, The Pennsylvania State University, 65 p.

Pattridge, K. A., 1979, The Gannett Peak lineament: A passive element during Laramide uncoupling of the Wyoming foreland; in Proceedings of the 2nd International Conference on Basement Tectonics (Podwysocki, M. H., and Earle, J. L., eds.), Basement Tectonics Committee, Denver, Colorado, p. 145-156.

Pennsylvania Geological Survey, 1960, Geological Map of Pennsylvania, scale 1:250,000.

Prucha, J. J., 1968, Salt deformation and decollement in the Firtree Point anticline of central New York; Tectonophysics, v. 6, p. 273-299.

Revetta, F. A., and Diment, W. H., 1971, Simple Bouger gravity anomaly map of western New York; New York State Museum and Science Service, Geological Survey, Map and Chart Series No. 17, scale 1:250,000.

Rickard, L. V., 1969, Stratigraphy of the Upper Silurian Salina Group, New York, Pennsylvania, Ohio, Ontario; New York State Museum and Science Service, Geological Survey, Map and Chart Series No. 12, 57 p. 14 plates.

______________ 1973, Stratigraphy and structure of the subsurface Cambrian and Ordovician carbonates of New York; New York State Museum and Science Service, Geological Survey, Map and Chart Series No. 18, 25 p., 19 plates.

Rickard, L. V., and Fisher, D. W., 1970, Geologic Map of New York, Finger Lakes sheet; New York State Museum and Science Service, Geological Survey, Map and Chart Series No. 15, scale 1:250,000.

Rodgers, John, 1949, Evolution of thought on structure of middle and southern Appalachians; American Association of Petroleum Geologists Bulletin, v. 33, p. 1643-1654.

______________ 1963, Mechanics of Appalachian foreland folding in Pennsylvania and West Virginia; American Association of Petroleum Geologists Bulletin, v. 47, p. 1527-1536.

______________ 1964, Basement and no-basement hypotheses in the Jura and the Appalachian Valley and Ridge, in Tectonics of the Southern Appalachians; Virginia Polytechnic Institute, Department of Geological Sciences, Memoir 1, p. 71-80.

_______________ 1970, The Tectonics of the Appalachians; Wiley-Interscience, New York, 271 p.

Sawatzky, D. L., and Raines, G. L., in press, Geologic uses of linear-feature maps derived from small-scale maps, in Proceedings of the 3rd International Conference on Basement Tectonics, (O'Leary, D.W., eds.), Basement Tectonics Committee, Denver, Colorado.

Sawatzky, D. L., and Townsend, T. E., 1976, Programmer's guide for REMAPP remote sensing array processing procedures; U. S. Department of Commerce, National Technical Information Service, PB-256693, 39 p.

Sheldon, P. G., 1927, On the association of faulting with dike intrusion; Journal of Geology, v. 35, p. 353-367.

Shurr, G. W., 1979, Lineament control of sedimentary facies in the northern Great Plains, in Proceedings of the 2nd International Conference on Basement Tectonics, (Podwysocki, M. H., and Earle, J. L., eds.); Basement Tectonics Committee, Denver, Colorado, p. 413-422.

Simmons, G., and Diment, W. H., 1973, Simple Bouger gravity anomaly map of northern New York; New York State Museum and Science Service, Geological Survey, Map and Chart Series No. 17a, scale 1:250,000.

Simpson, Frank, 1979, Evolution of a graded Cretaceous shelf, in Proceedings of the 2nd International Conference on Basement Tectonics (Podwysocki, M. H., and Earle, J. L., eds.); Basement Tectonics Committee, Denver, Colorado, p. 423-434.

Sloss, L.L., Krumbein, W.C., and Dapples, E.C., 1949, Integrated facies analysis, in Sedimentary Facies in Geologic History (Longwell, C.R., ed.); Geological Society of America Memoir 39, p. 91-123.

Sutton, R.G., 1963, Stratigraphy in the Appalachian and Binghamton quadrangles, in Geology of South-central New York; Guidebook for the 35th Annual Meeting of the New York State Geological Association, p. 77-78.

Thompson, A. M. and Hager, G. M., 1979, Lineament studies in structural interpretation of a stabilized orogenic region: Appalachian Piedmont, Deleware and adjacent Pennsylvania, in Proceedings of the 2nd International Conference on Basement Tectonics (Podwysocki, M. H. and Earle, J. L., eds.); Basement Tectonics Committee, Denver, Colorado, p. 74-85.

Trifonov, V. G., Makarov, V. I., Derevyanko, O. S., Panin, V. M., Petrenko, A. S., Skobelev, S. F., Florensky, P. V., and Shorin-Konstantinov, B. P., 1978, Geologicheskoe Izuchenie Zemli iz Kosmosa (Geological Study of the Earth from Space) (in Russian), Akad Nauk SSSR, Ordena Trudnovo Krasnovo Znameni Geologicheskii Institut, Trudy, Vyp. 317, Izd. NEDRA, Leningrad, 228 p.

Twigg, D. B., 1961, The stratigraphic and structural geology of the Corning quadrangle, New York; unpublished Master of Science Thesis, University of Rochester, 61 p.

Urban, T. C., Bromery, R. W., Revettor, F. A., and Diment, W. H., 1973, Simple Bouger gravity anomaly map of southeastern New York and contiguous states; New York State Museum and Science Service, Geological Survey, Map and Chart Series No. 17c, scale 1:250,000.

U.S. Geological Survey, 1975, Aeromagnetic map of westernmost New York, U.S. Geological Survey Open File Report 75-28, scale 1:250,000.

U.S. Geological Survey, 1977, Aeromagnetic map of parts of the Rochester and Utica 1^{o} x 2^{o} quadrangles, New York; U.S. Geological Survey Open File Report 77-553, scale 1:250,000.

U.S. Geological Survey, 1978, Aeromagnetic map of Pennsylvania; U.S. Geological Survey Geophysical Investigations Map GP-924, scale 1:250,000, 2 sheets.

U.S. Geological Survey, 1979, Aeromagnetic map of central New York; U.S. Geological Survey Open File Report 79-653, scale 1:250,000.

Vanuxem, Lardner, 1842, Report on the Third Geological District, Part III, 306 p.

Von Engeln, O. D., 1961, The Finger Lakes Region: Its Origin and Nature (1st ed.); Cornell University Press, 156 p.

Vozoff, K., 1951, Gravity investigations in north-central Pennsylvania; unpublished Master of Science thesis, The Pennsylvania State University, 52 p.

Wedel, A. A., 1932, Geologic structure of the Devonian strata of south-central New York; New York State Museum, Bulletin 294, 74 p.

Wheeler, R. L., Winslow, M., Horne, R. R., Dean, S., Kulander, B., Drahovzal, J. A., Gold, D. P., Gilbert, O. E., Jr., Werner, E., Sites, R., and Perry, W. J., 1979, Cross-strike structural discontinuities in thrust belts, mostly Appalachian; Southeastern Geology, v. 20, p. 193-203.

Williams, H. S., Tarr, R. S. and Kindle, E. M., 1909, Watkins Glen and Catatonk (quadrangles), New York; U.S. Geological Survey Atlas of the United States, Folio 169, 33 p.

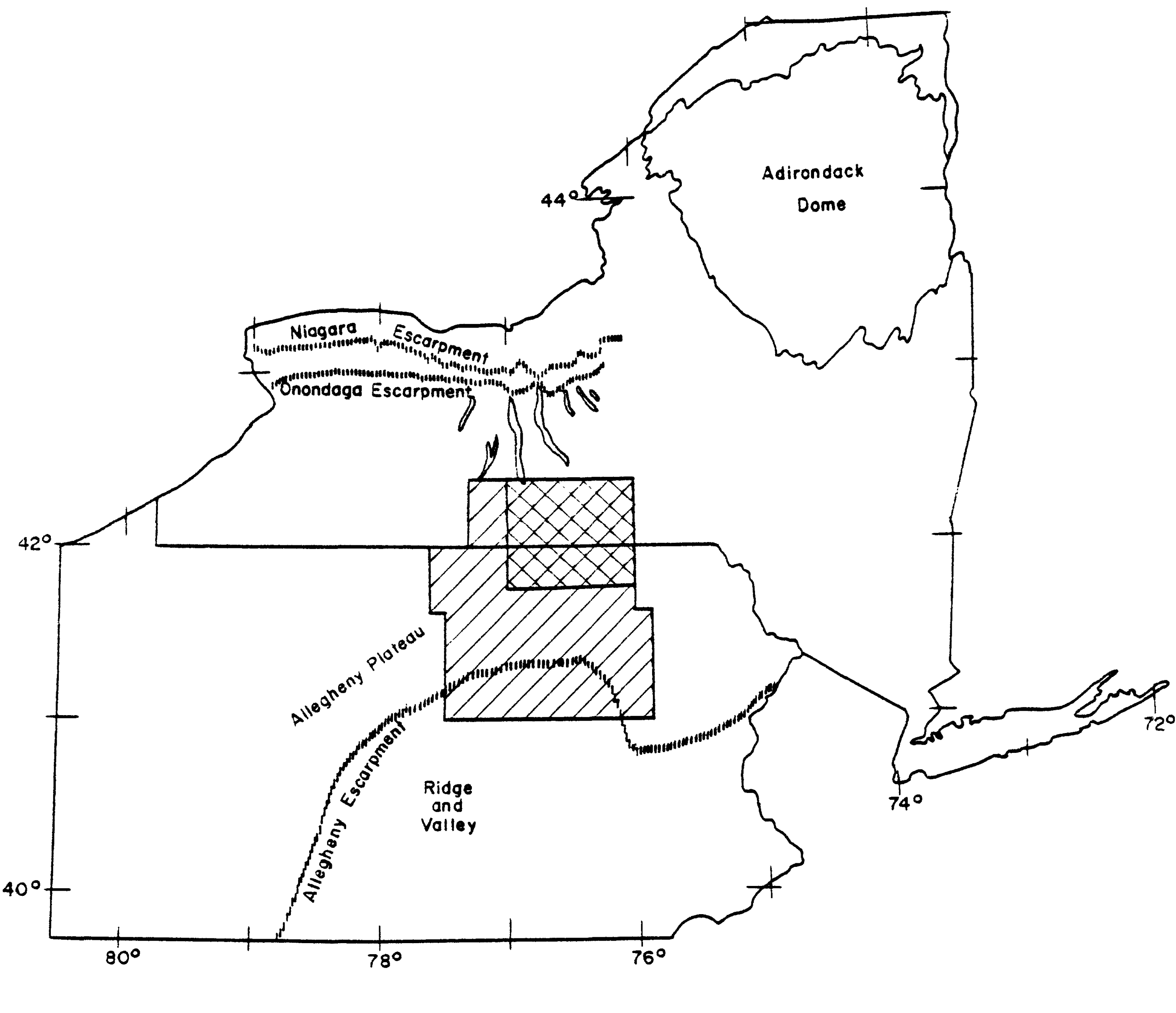
Wilson, C.W., Jr., and Stearns, R.G., 1958, Structure of the Cumberland Plateau, Tennessee; Geological Society of America Bulletin, v. 69, p. 1283-1296.

Wright, N. A., 1973, Subsurface Tully Limestone, New York and Pennsylvania, New York State Museum and Science Service, Geological Survey, Map and Chart Series No. 14, 15 p., 2 plates.

Woodrow, D. L., 1968, Stratigraphy, structure and sedimentary patterns in the Upper Devonian of Bradford County, Pennsylvania; Pennsylvania Geological Survey Bulletin G54, 78 p.

Zartmann, R. E., Brock, M. R., Heyl, A. V., and Thomas, H. H., 1967, K-Ar and Rb-Sr ages of some alkalic intrusive rocks from central and eastern United States; American Journal of Science, v. 265, p. 848-870.

Zerrahn, G. J., 1978, Ordovician (Trenton to Richmond) depositional patterns of New York State, and their relation to the Taconic orogeny; Bulletin of the Geological Society of America, v. 89, p. 1751-1760.



Adirondack
Dome
44°
Niagara
Escarpment
Onondaga Escarpment
42°
Allegheny Plateau
Allegheny Escarpment
Ridge
and
Valley
40°
80°
78°
76°
74°
72°

Figure 1

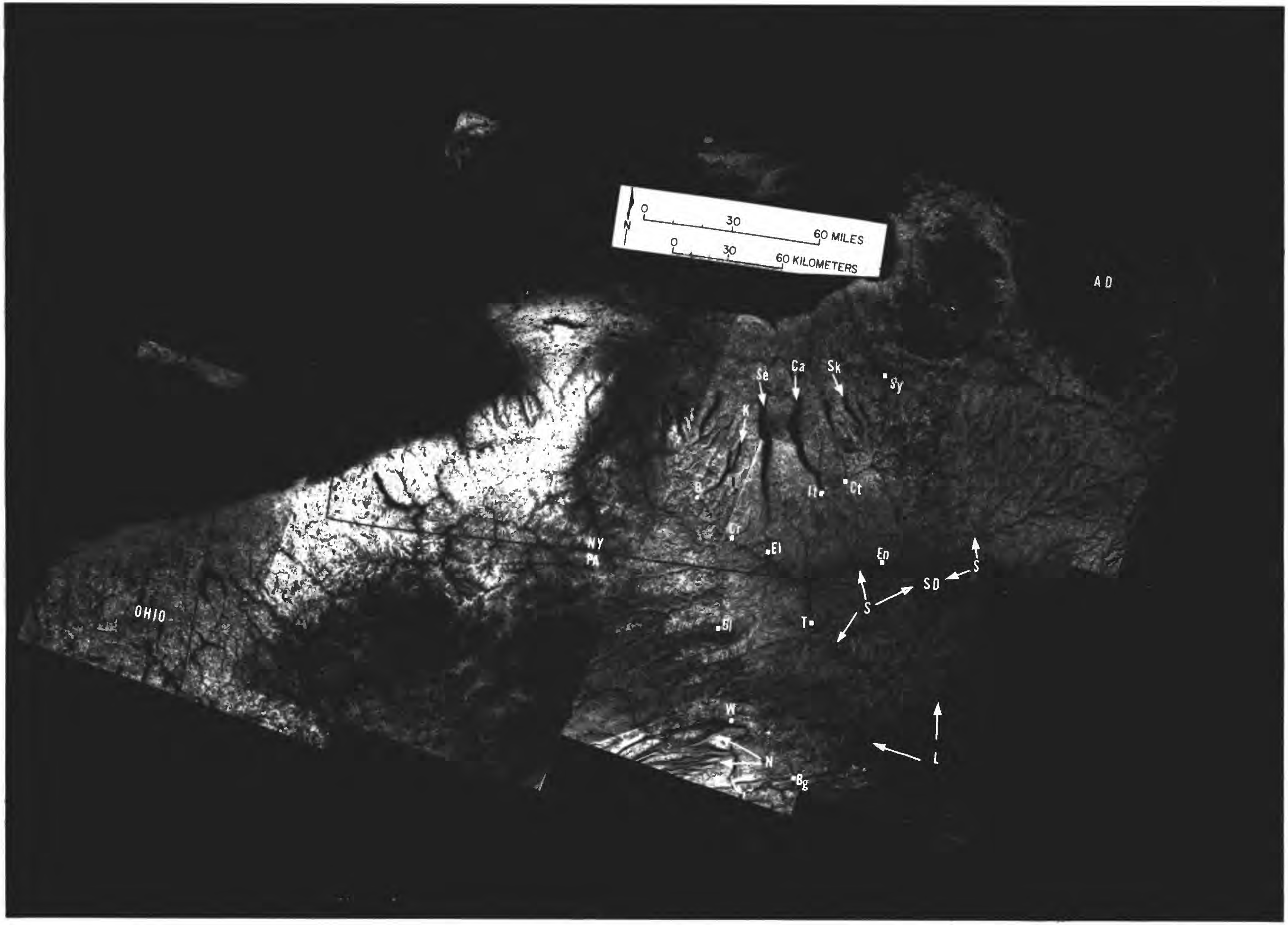

N
0 30 60 MILES
0 30 60 KILOMETERS
AD
Se
Ca
Sk
Sy
K
B
It
Ct
Cr
El
En
S
SD
S
NY
PA
OHIO
Bl
T
W
N
Bg
L

Figure 2a

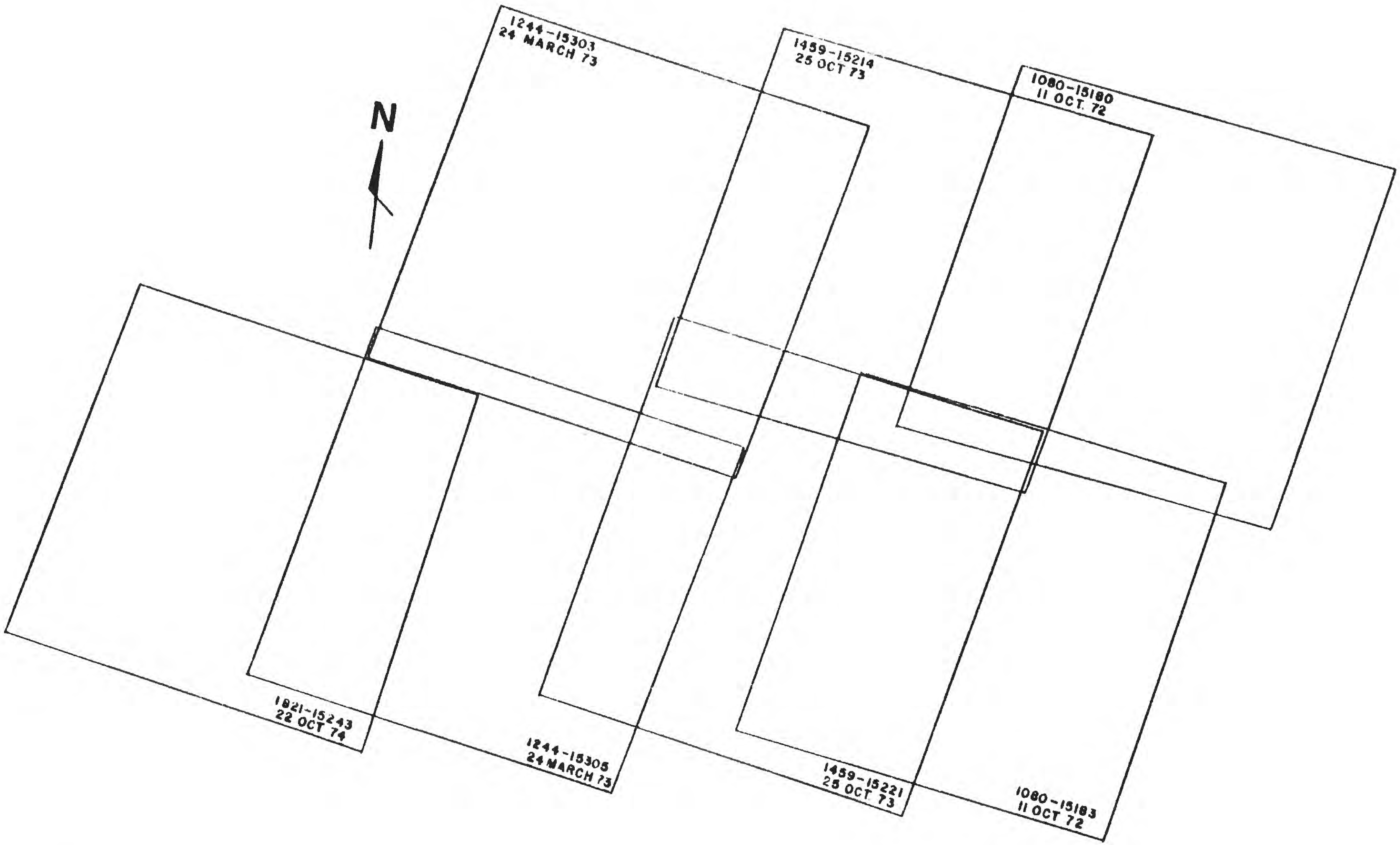

N
1244-15303
24 MARCH 73
1459-15214
25 OCT 73
1080-15180
11 OCT. 72
1821-15243
22 OCT 74
1244-15305
24 MARCH 73
1459-15221
25 OCT. 73
1080-15183
11 OCT 72

Figure 2b

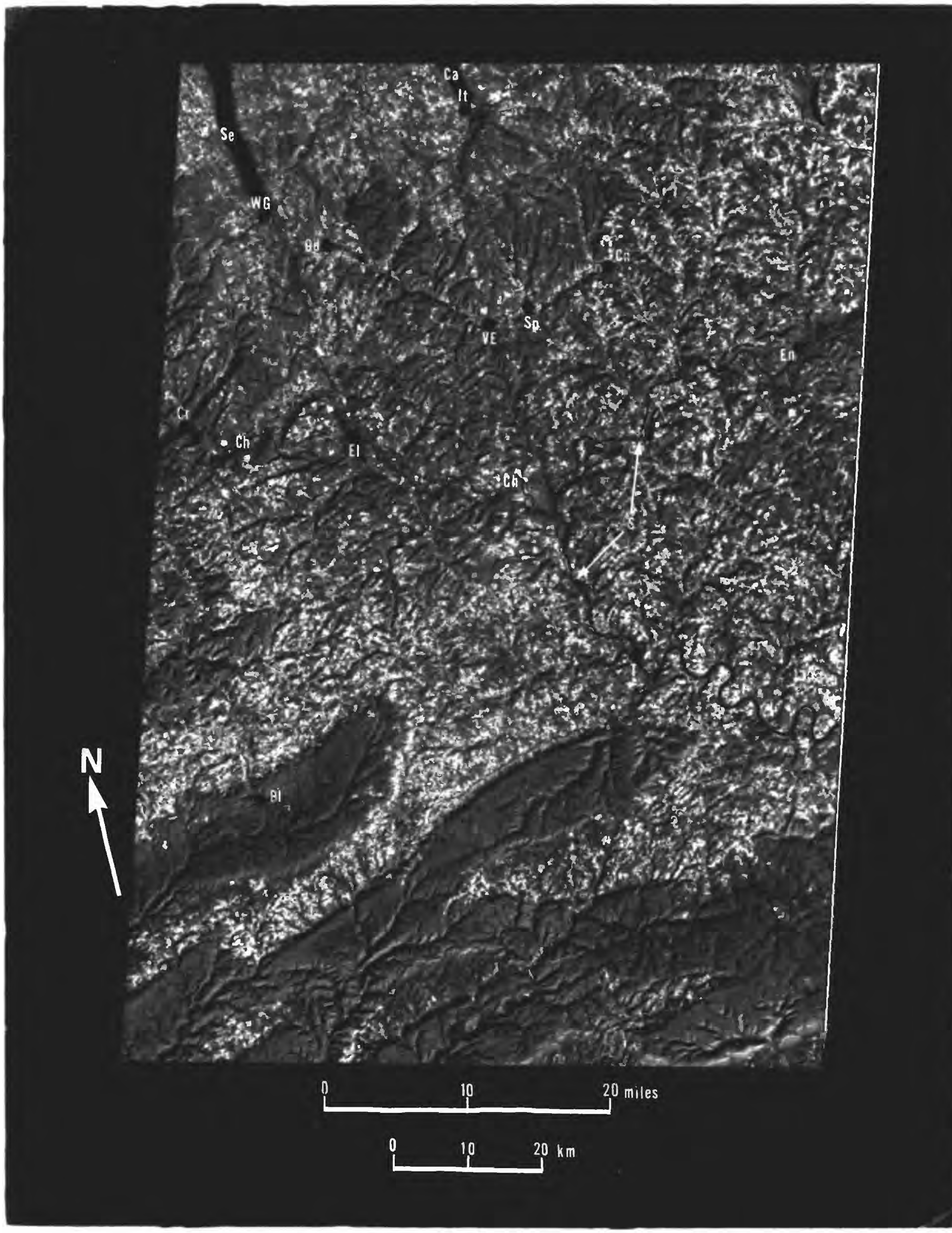


Figure 3

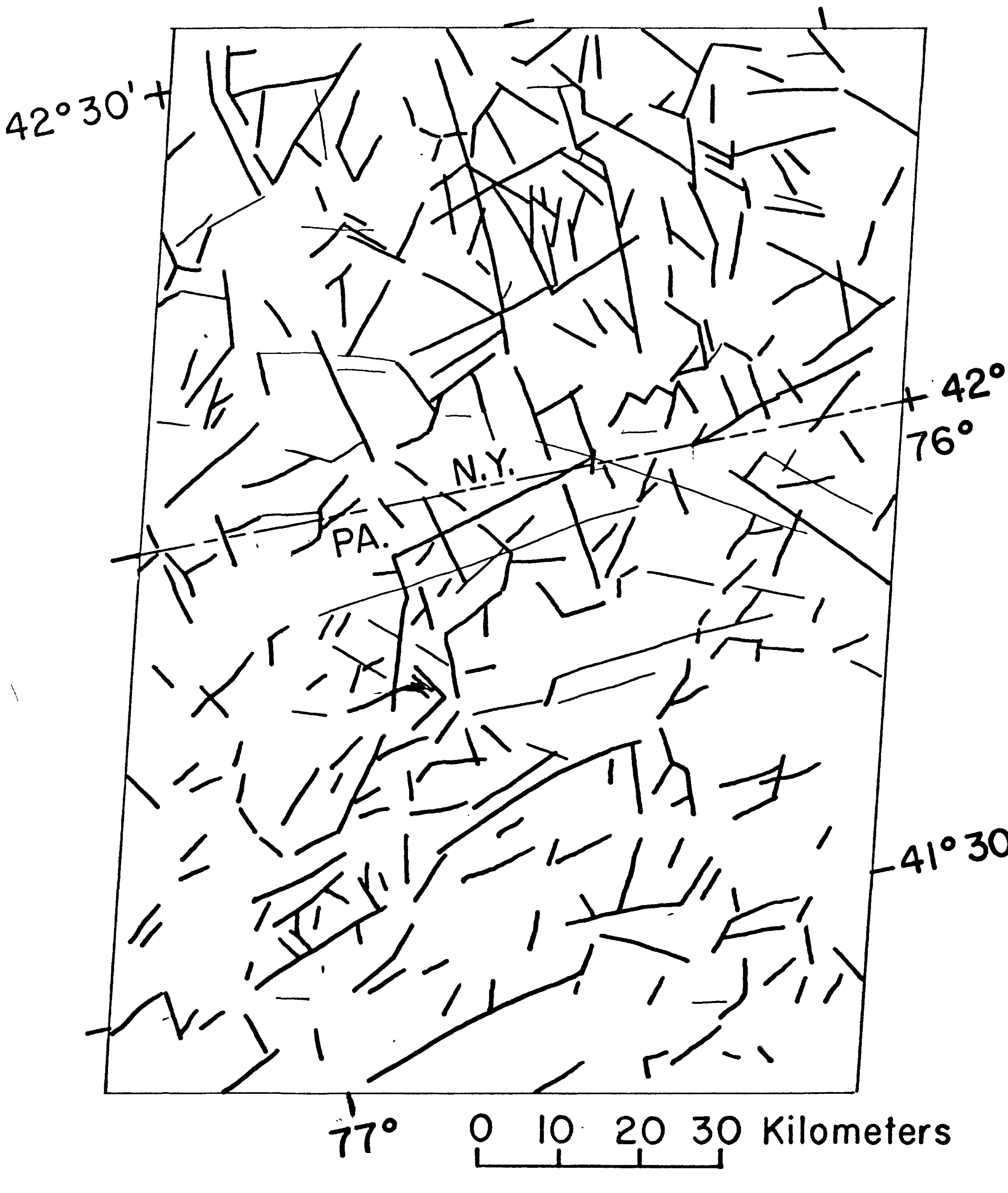


Figure 4

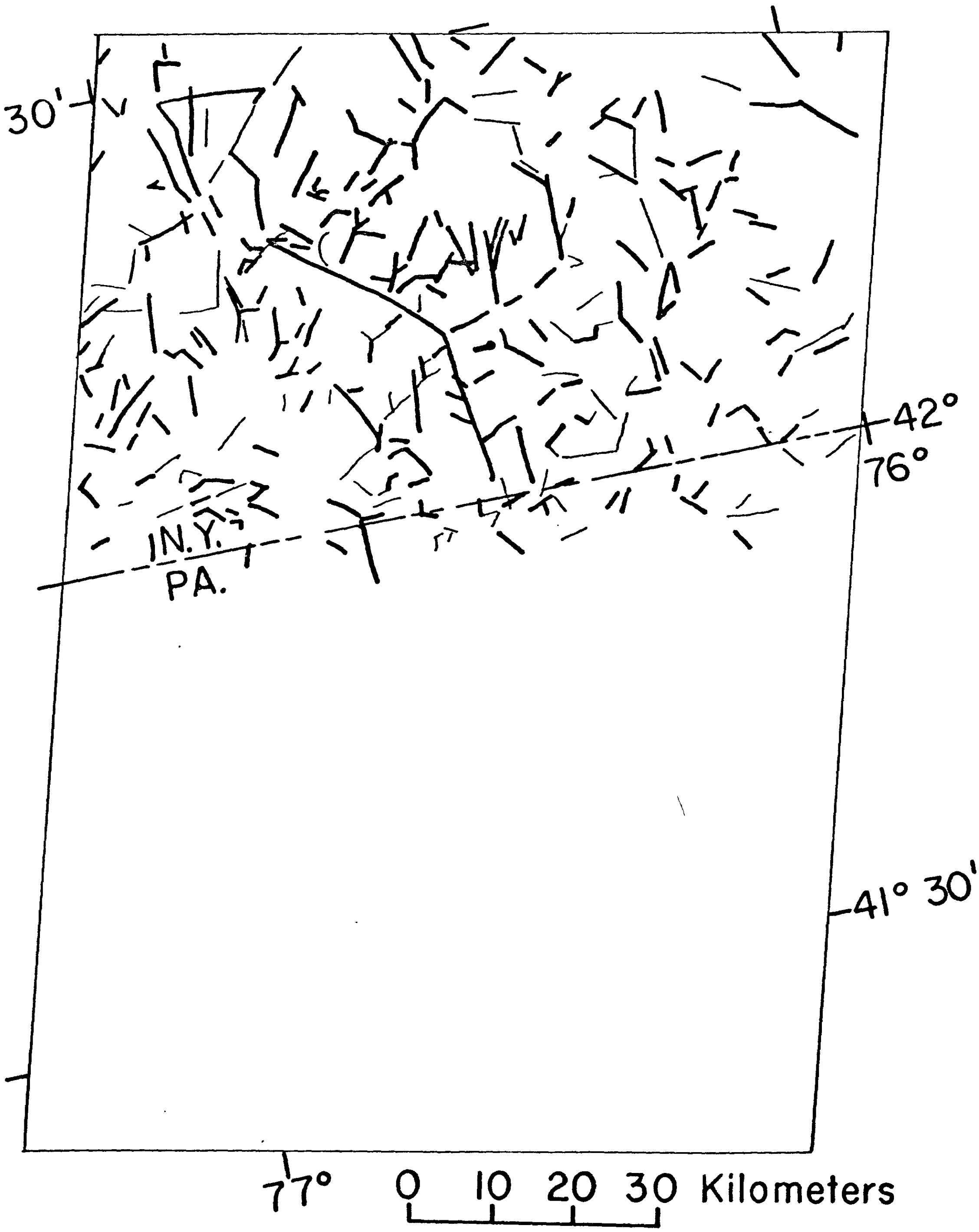


Figure 5

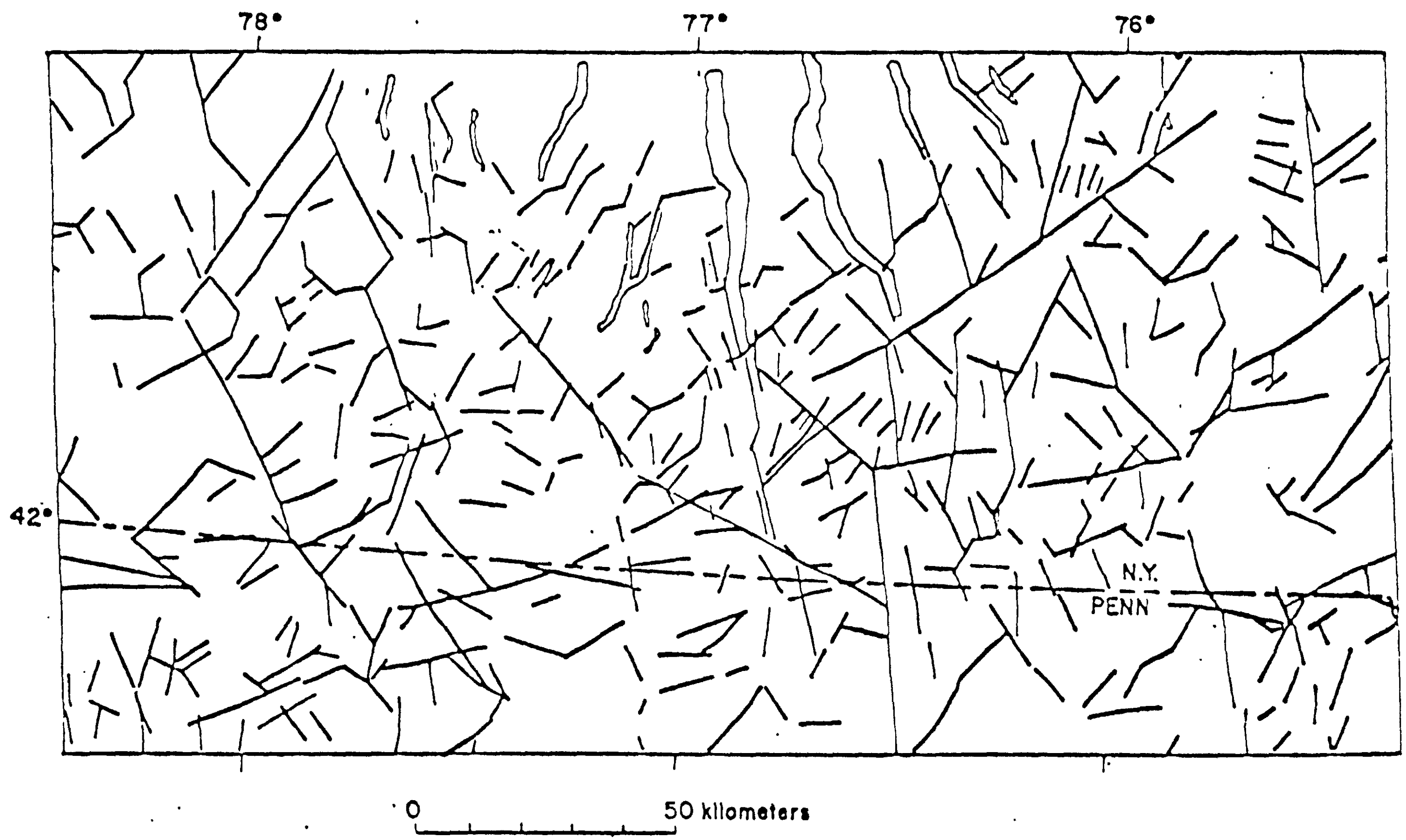


Figure 6

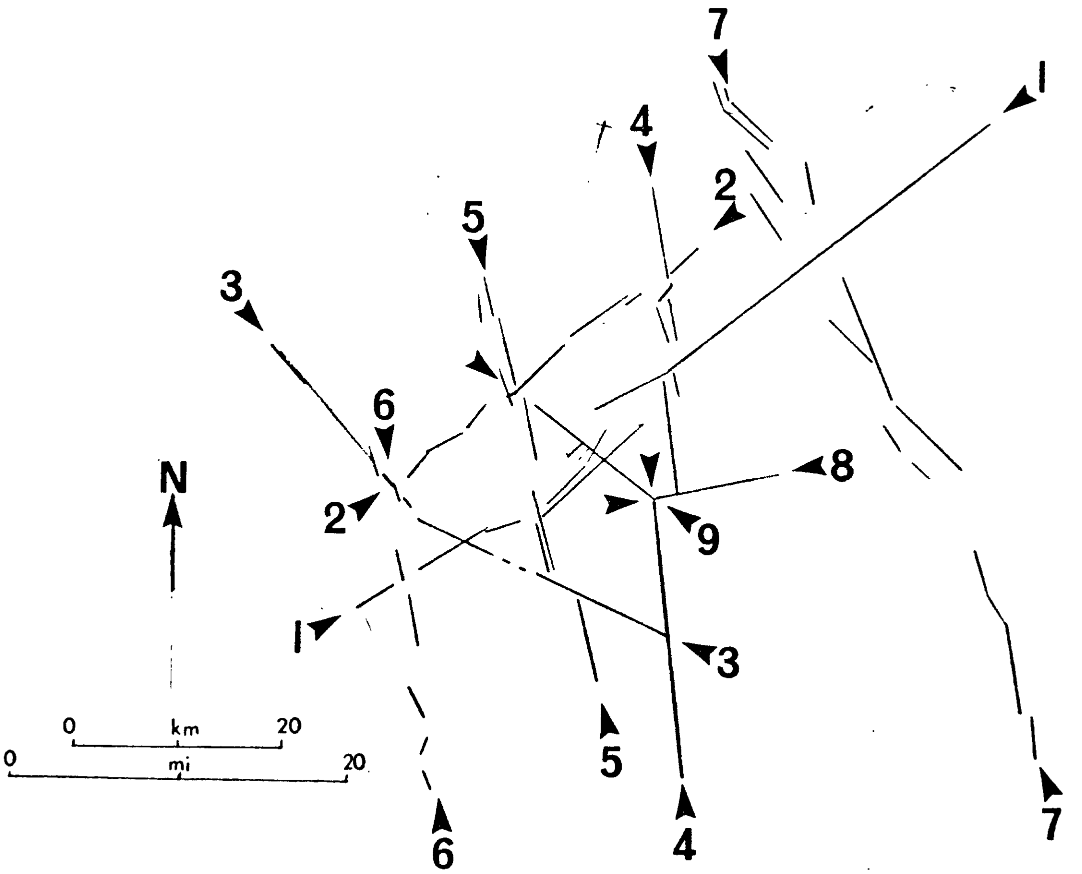


Figure 7

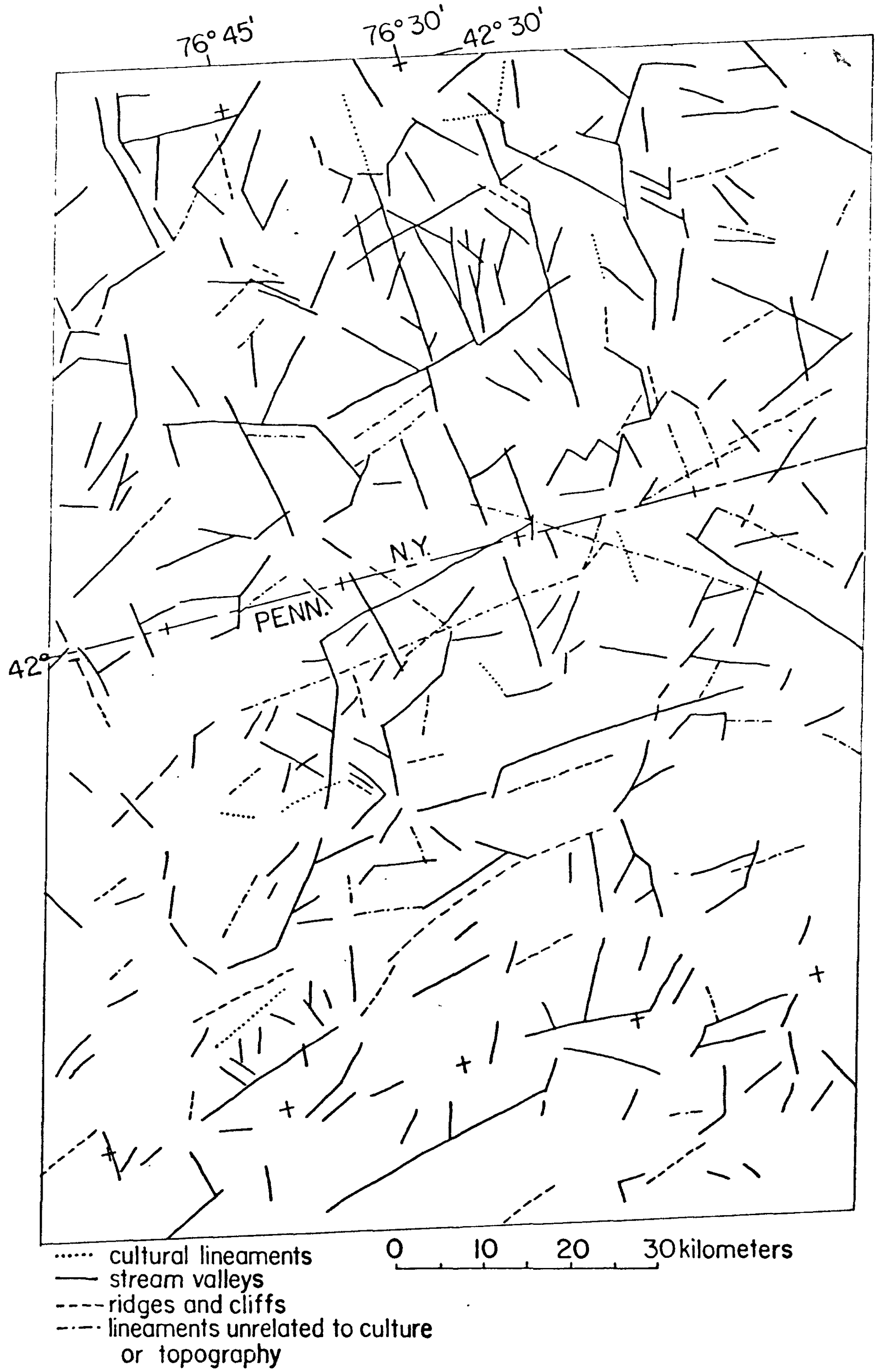
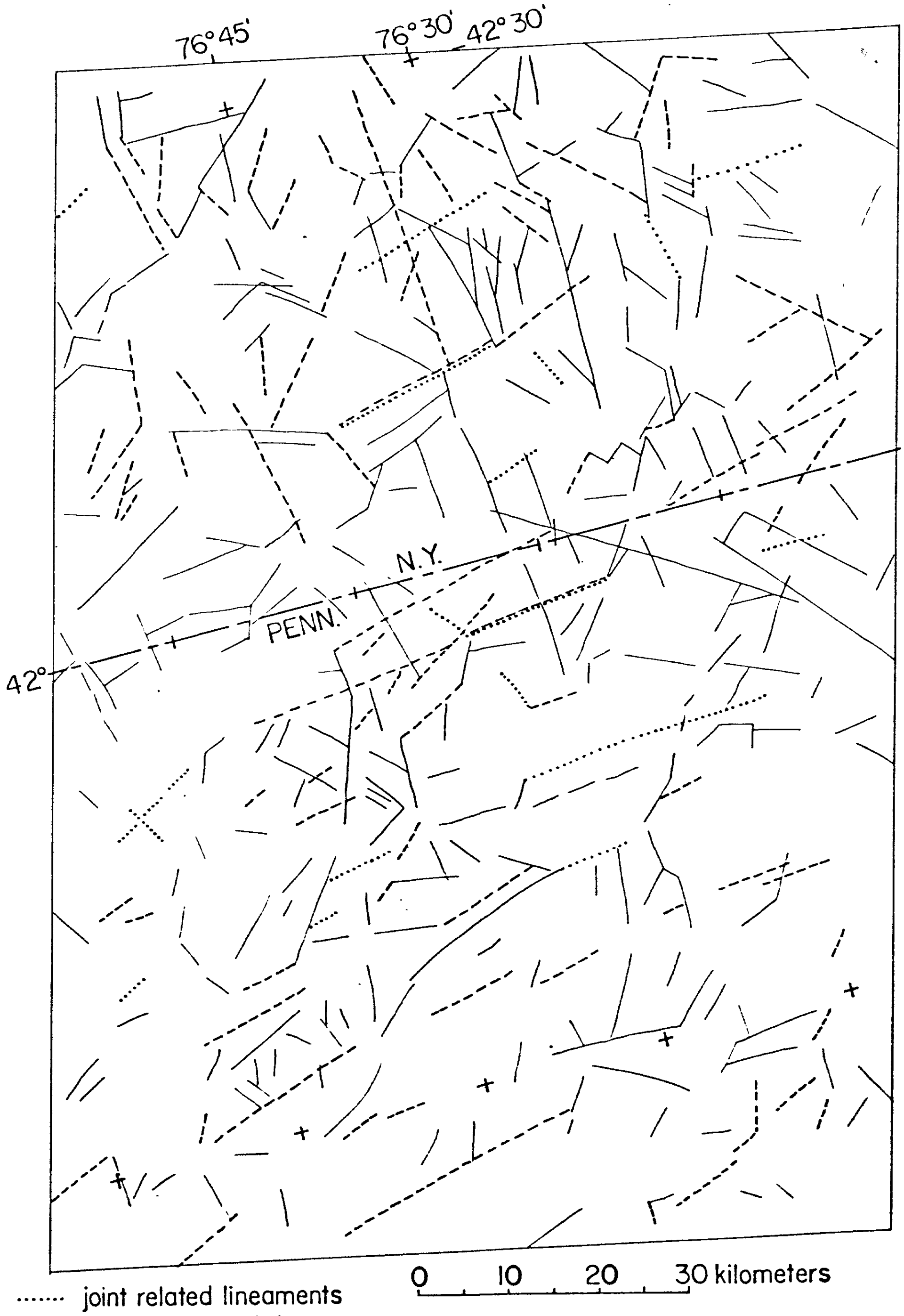

76° 45'
76° 30'
42° 30'
N.Y.
PENN.
42°
0 10 20 30 kilometers
cultural lineaments
stream valleys
ridges and cliffs
lineaments unrelated to culture or topography

Figure 8



······ joint related lineaments
---- glacially related lineaments

Figure 9

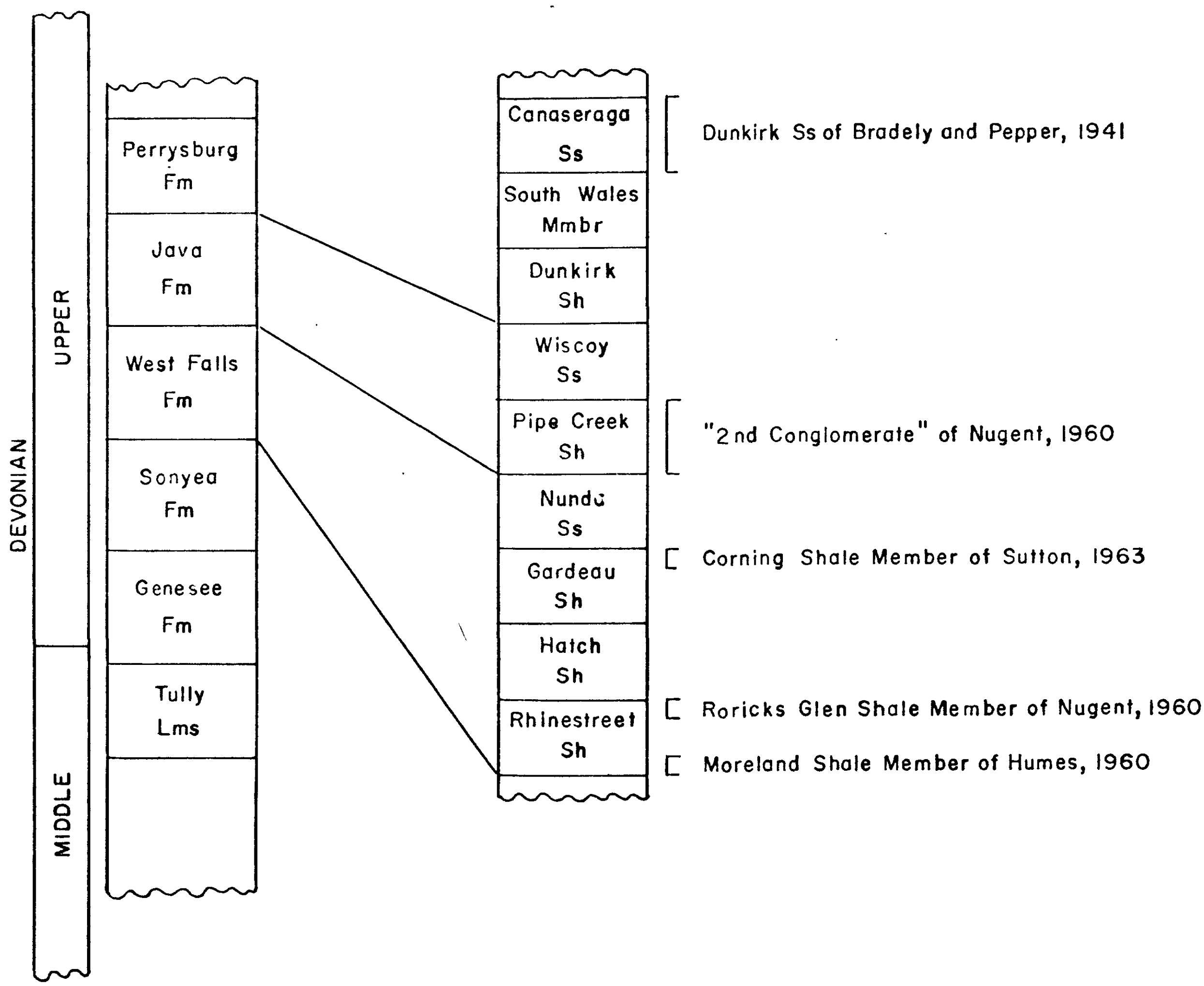
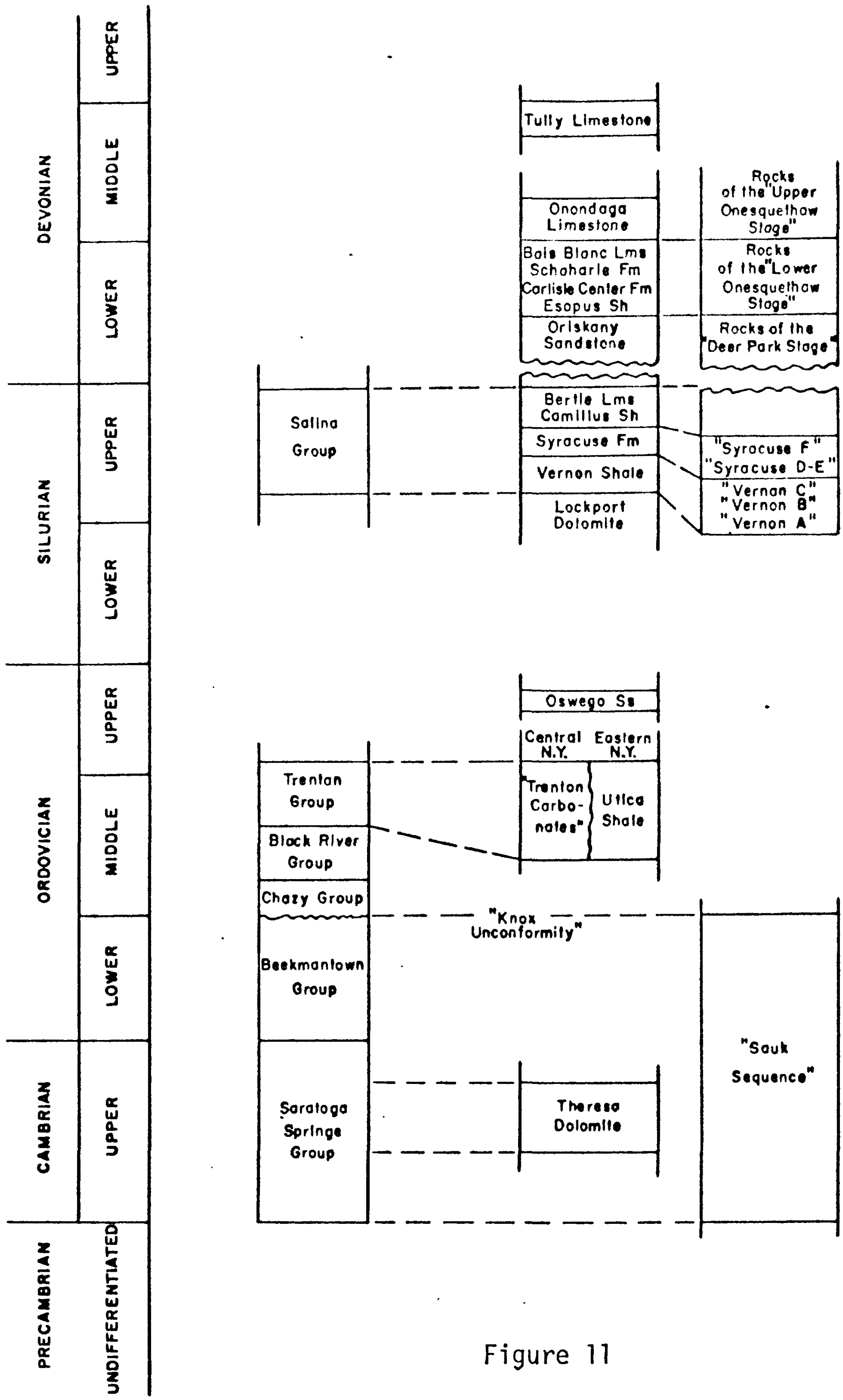

DEVONIAN
UPPER
MIDDLE
Perrysburg Fm
Java Fm
West Falls Fm
Sonyea Fm
Genesee Fm
Tully Lms
Canaseraga Ss
South Wales Mmbr
Dunkirk Sh
Wiscoy Ss
Pipe Creek Sh
Nunda Ss
Gardeau Sh
Hatch Sh
Rhinestreet Sh
Dunkirk Ss of Bradely and Pepper, 1941
"2nd Conglomerate" of Nugent, 1960
Corning Shale Member of Sutton, 1963
Roricks Glen Shale Member of Nugent, 1960
Moreland Shale Member of Humes, 1960

Figure 10



DEVONIAN
UPPER
MIDDLE
LOWER
SILURIAN
UPPER
LOWER
ORDOVICIAN
UPPER
MIDDLE
LOWER
CAMBRIAN
UPPER
PRECAMBRIAN
UNDIFFERENTIATED
Tully Limestone
Onondaga Limestone
Bois Blanc Lms
Schoharie Fm
Carlisle Center Fm
Esopus Sh
Oriskany Sandstone
Rocks of the "Upper Onesquethaw Stage"
Rocks of the "Lower Onesquethaw Stage"
Rocks of the "Deer Park Stage"
Salina Group
Bertie Lms
Camillus Sh
Syracuse Fm
Vernon Shale
Lockport Dolomite
"Syracuse F"
"Syracuse D-E"
"Vernon C"
"Vernon B"
"Vernon A"
Oswego Ss
Central N.Y.
Eastern N.Y.
Trenton Group
Black River Group
Chazy Group
"Trenton Carbonates"
Utica Shale
"Knox Unconformity"
Beekmantown Group
Saratoga Springs Group
Theresa Dolomite
"Sauk Sequence"

Figure 11

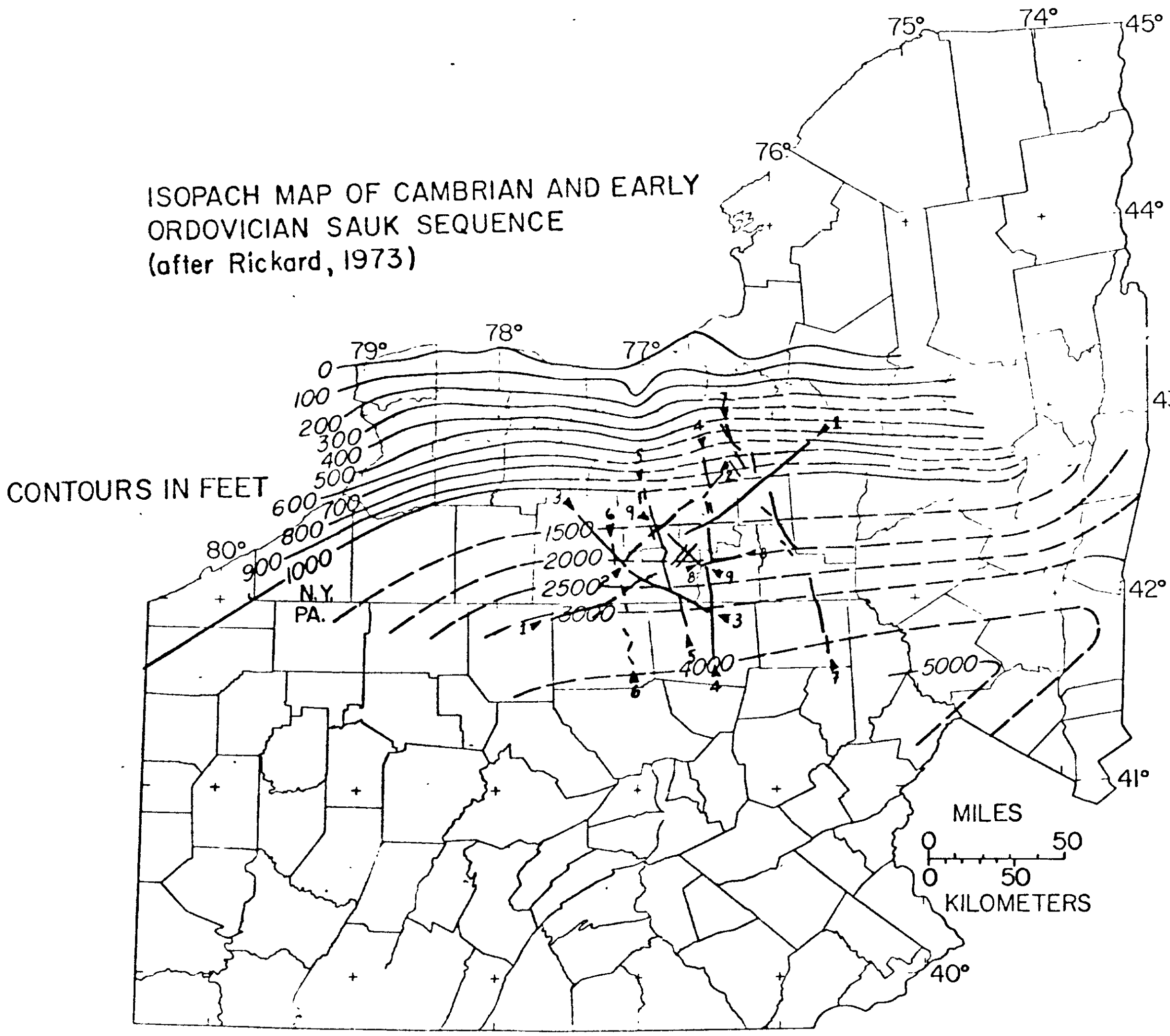

ISOPACH MAP OF CAMBRIAN AND EARLY ORDOVICIAN SAUK SEQUENCE
(after Rickard, 1973)
CONTOURS IN FEET
0
100
200
300
400
500
600
700
800
900
1000
1500
2000
2500
3000
4000
5000
N.Y.
PA.
75°
74°
45°
76°
44°
79°
78°
77°
43°
80°
42°
41°
40°
MILES
0
50
0
50
KILOMETERS

Figure 12

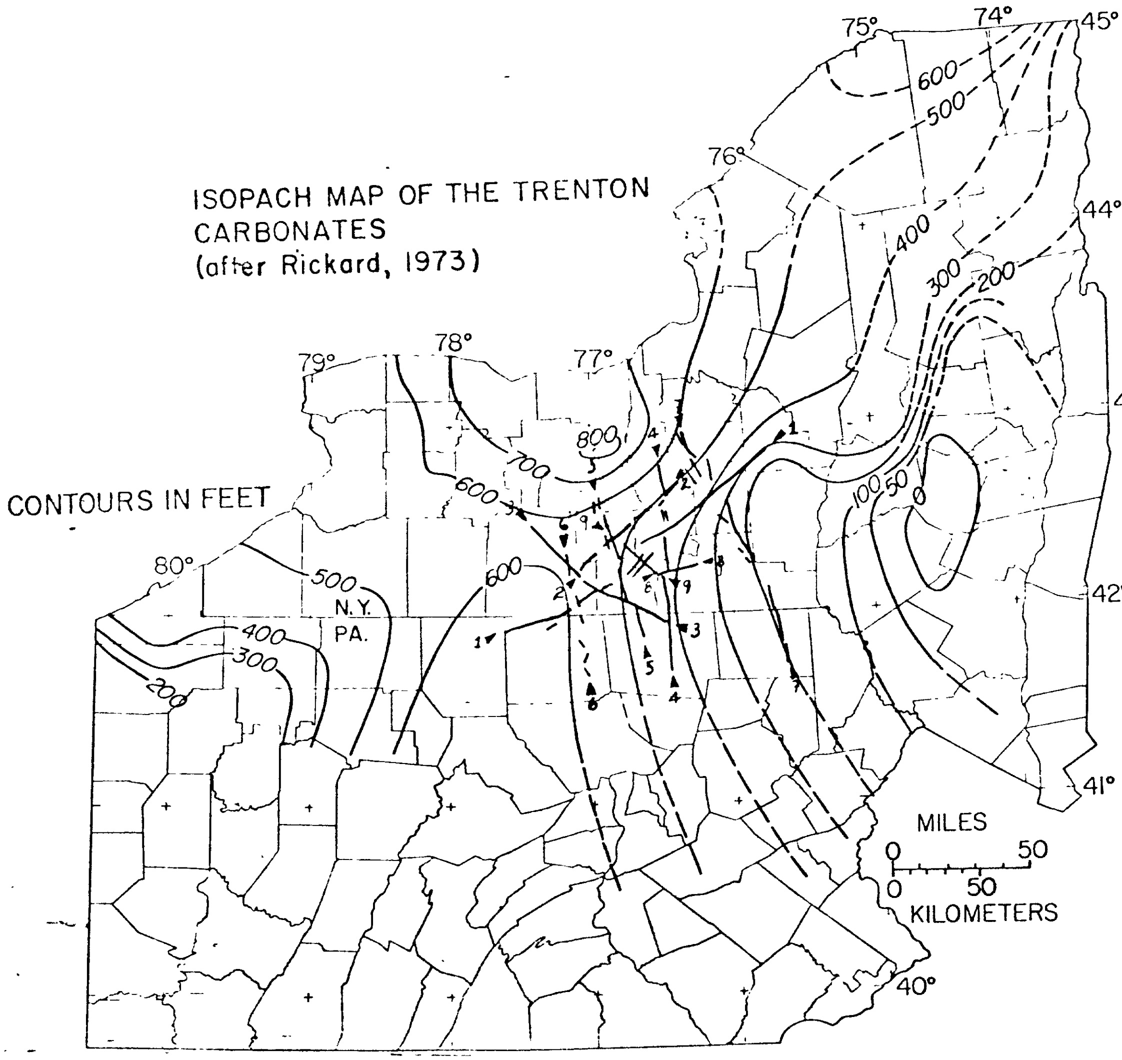

ISOPACH MAP OF THE TRENTON CARBONATES
(after Rickard, 1973)
CONTOURS IN FEET
N.Y.
PA.
MILES
0 50
0 50
KILOMETERS
75°
74°
45°
76°
44°
78°
79°
77°
43°
80°
42°
41°
40°
600
500
400
300
200
800
700
600
500
400
300
200
100
50
0

Figure 13

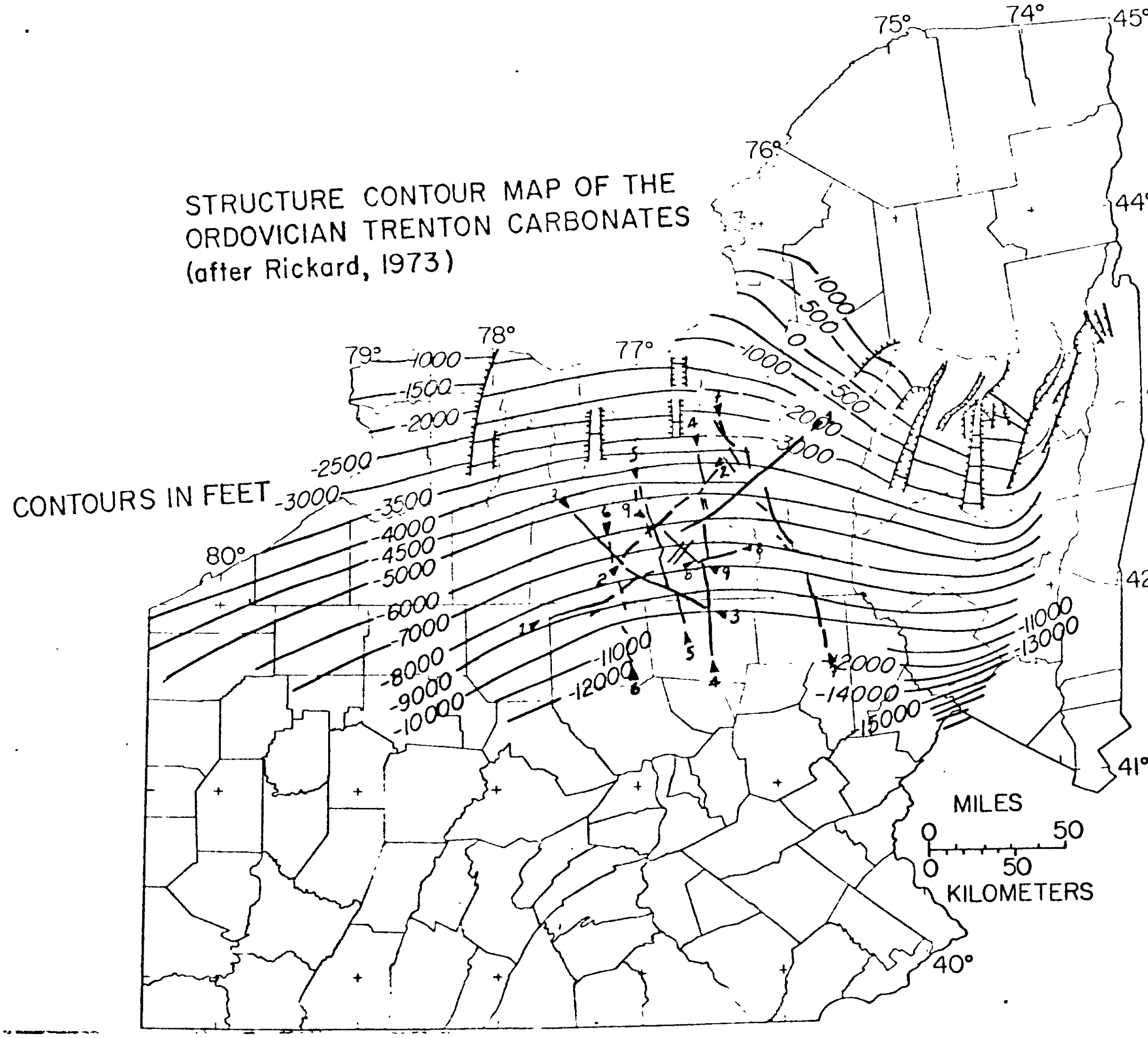

STRUCTURE CONTOUR MAP OF THE
ORDOVICIAN TRENTON CARBONATES
(after Rickard, 1973)
CONTOURS IN FEET
MILES
0
50
0
50
KILOMETERS
75°
74°
45°
76°
44°
43°
42°
41°
40°
80°
79°
78°
77°
-1000
-1500
-2000
-2500
-3000
-3500
-4000
-4500
-5000
-6000
-7000
-8000
-9000
-10000
-11000
-12000
1000
500
0
-1000
-500
-2000
-3000
-11000
-13000
-12000
-14000
-15000

Figure 14

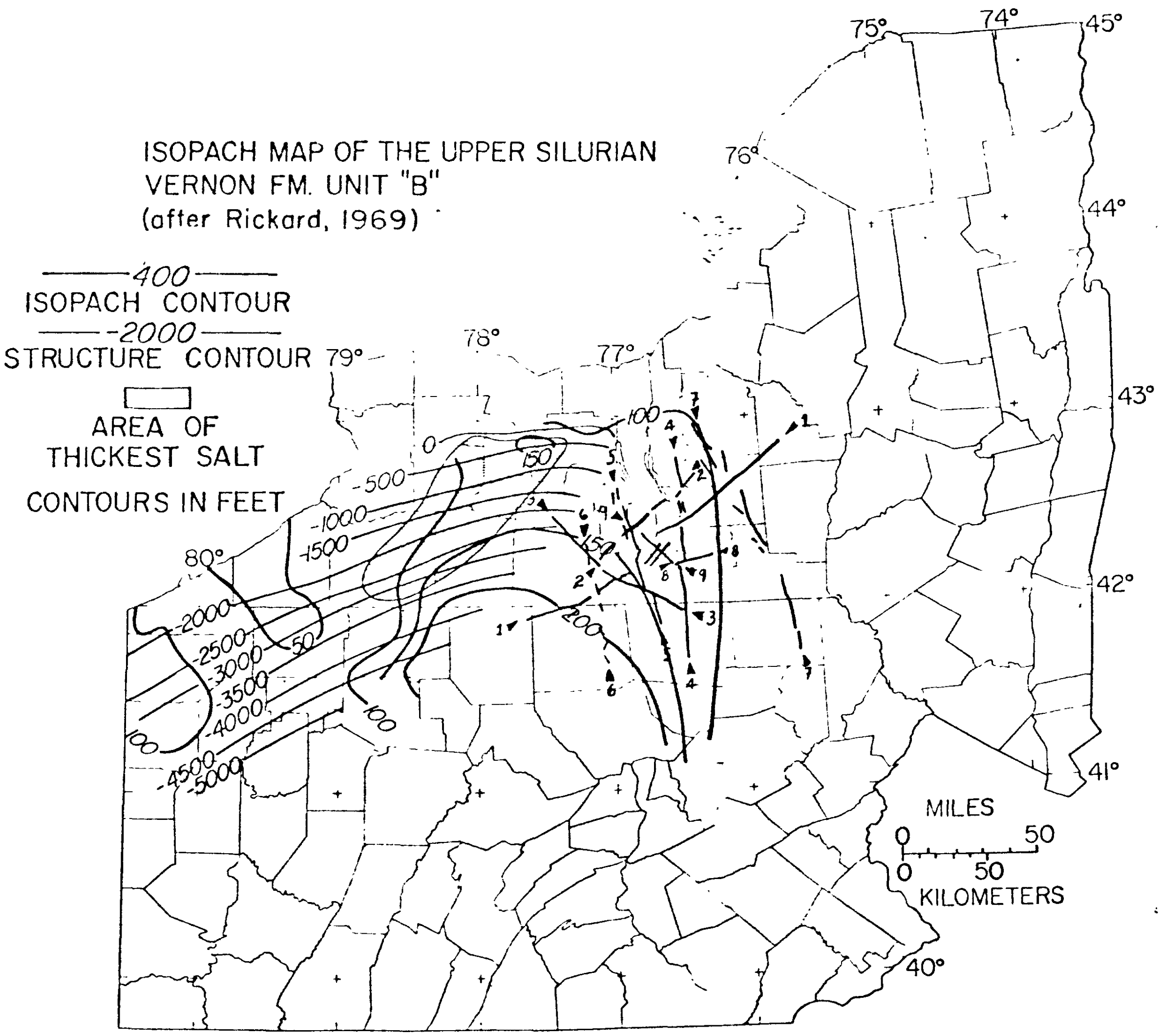

ISOPACH MAP OF THE UPPER SILURIAN
VERNON FM. UNIT "B"
(after Rickard, 1969)
400
ISOPACH CONTOUR
-2000
STRUCTURE CONTOUR
AREA OF
THICKEST SALT
CONTOURS IN FEET
MILES
0 50
0 50
KILOMETERS
75°
74°
45°
76°
44°
78°
77°
79°
43°
42°
80°
41°
40°

Figure 15

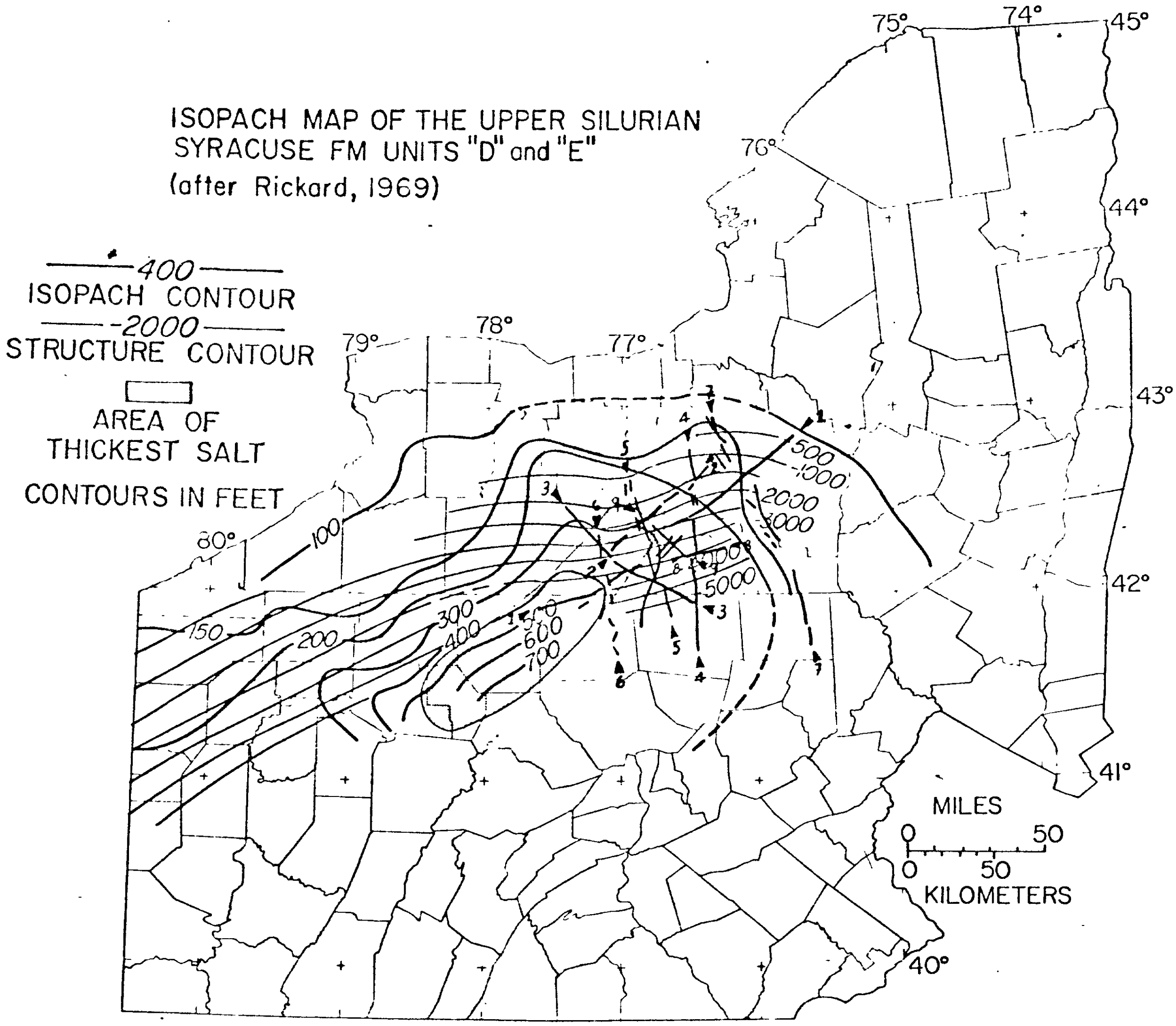

ISOPACH MAP OF THE UPPER SILURIAN
SYRACUSE FM UNITS "D" and "E"
(after Rickard, 1969)
400
ISOPACH CONTOUR
-2000
STRUCTURE CONTOUR
AREA OF
THICKEST SALT
CONTOURS IN FEET
75°
74°
45°
76°
44°
79°
78°
77°
43°
80°
42°
41°
40°
100
150
200
300
400
500
600
700
-1000
2000
3000
4000
5000
MILES
0
50
0
50
KILOMETERS

Figure 16

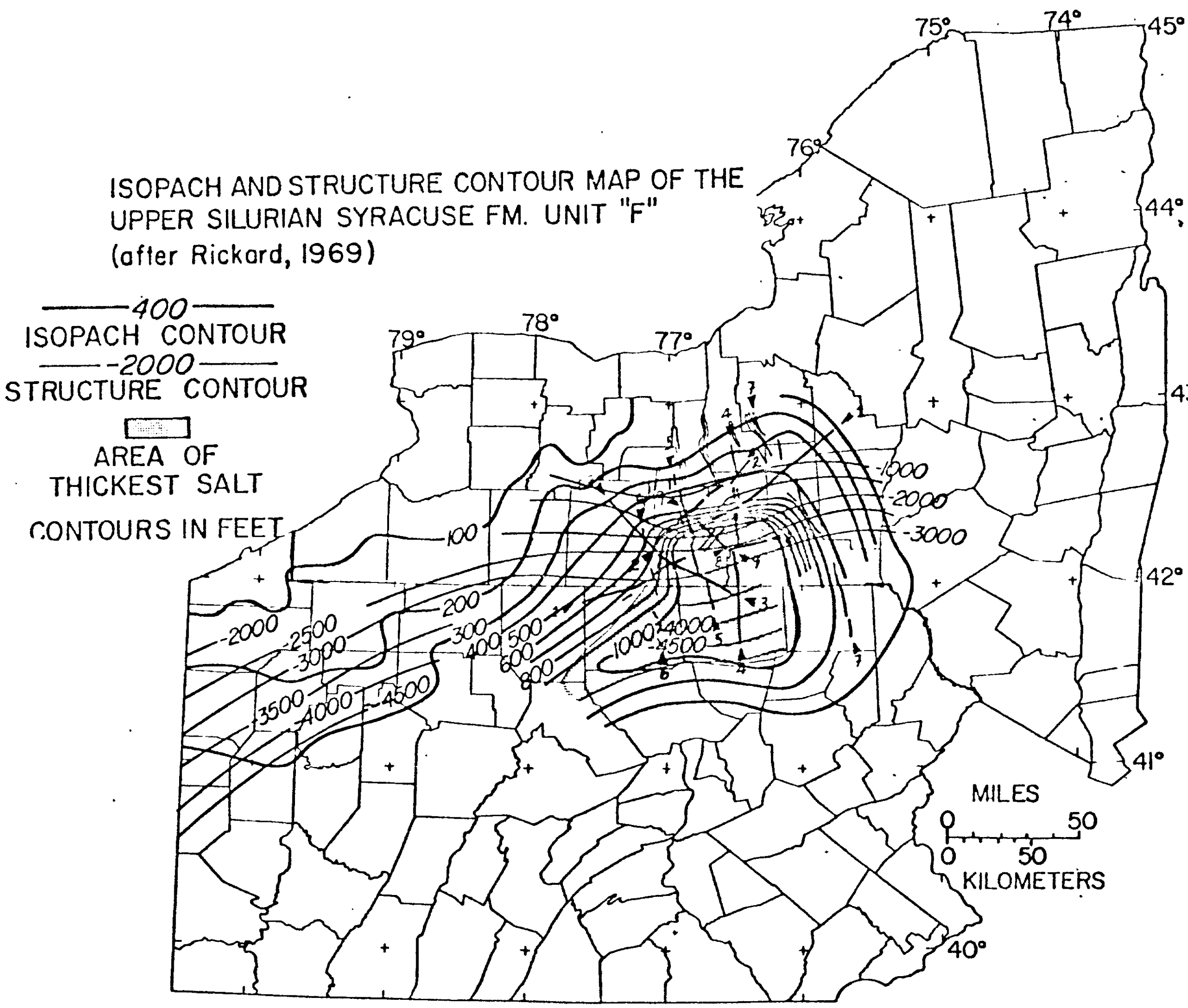

ISOPACH AND STRUCTURE CONTOUR MAP OF THE
UPPER SILURIAN SYRACUSE FM. UNIT "F"
(after Rickard, 1969)
400
ISOPACH CONTOUR
-2000
STRUCTURE CONTOUR
AREA OF
THICKEST SALT
CONTOURS IN FEET
MILES
0 50
0 50
KILOMETERS
75°
74°
45°
76°
44°
79°
78°
77°
43°
42°
41°
40°
100
200
300
400
500
600
800
1000
-1000
-2000
-3000
-2000
-2500
-3000
3500
-4000
-4500
-4000
-4500

Figure 17

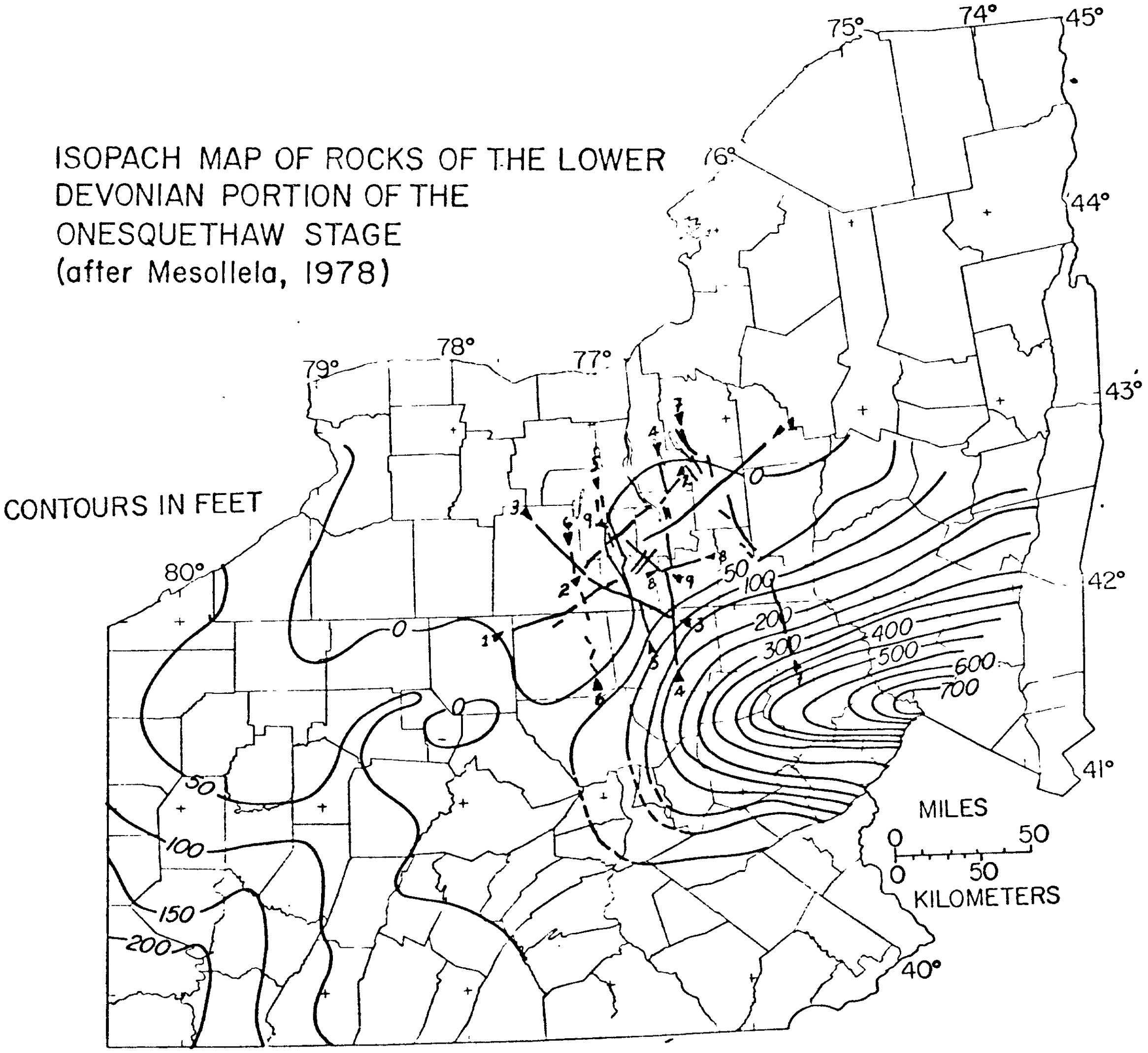

ISOPACH MAP OF ROCKS OF THE LOWER DEVONIAN PORTION OF THE ONESQUETHAW STAGE
(after Mesollela, 1978)
CONTOURS IN FEET
75°
74°
45°
76°
44°
43°
42°
41°
40°
79°
78°
77°
80°
MILES
0
50
0
50
KILOMETERS
0
50
100
150
200
300
400
500
600
700

Figure 18

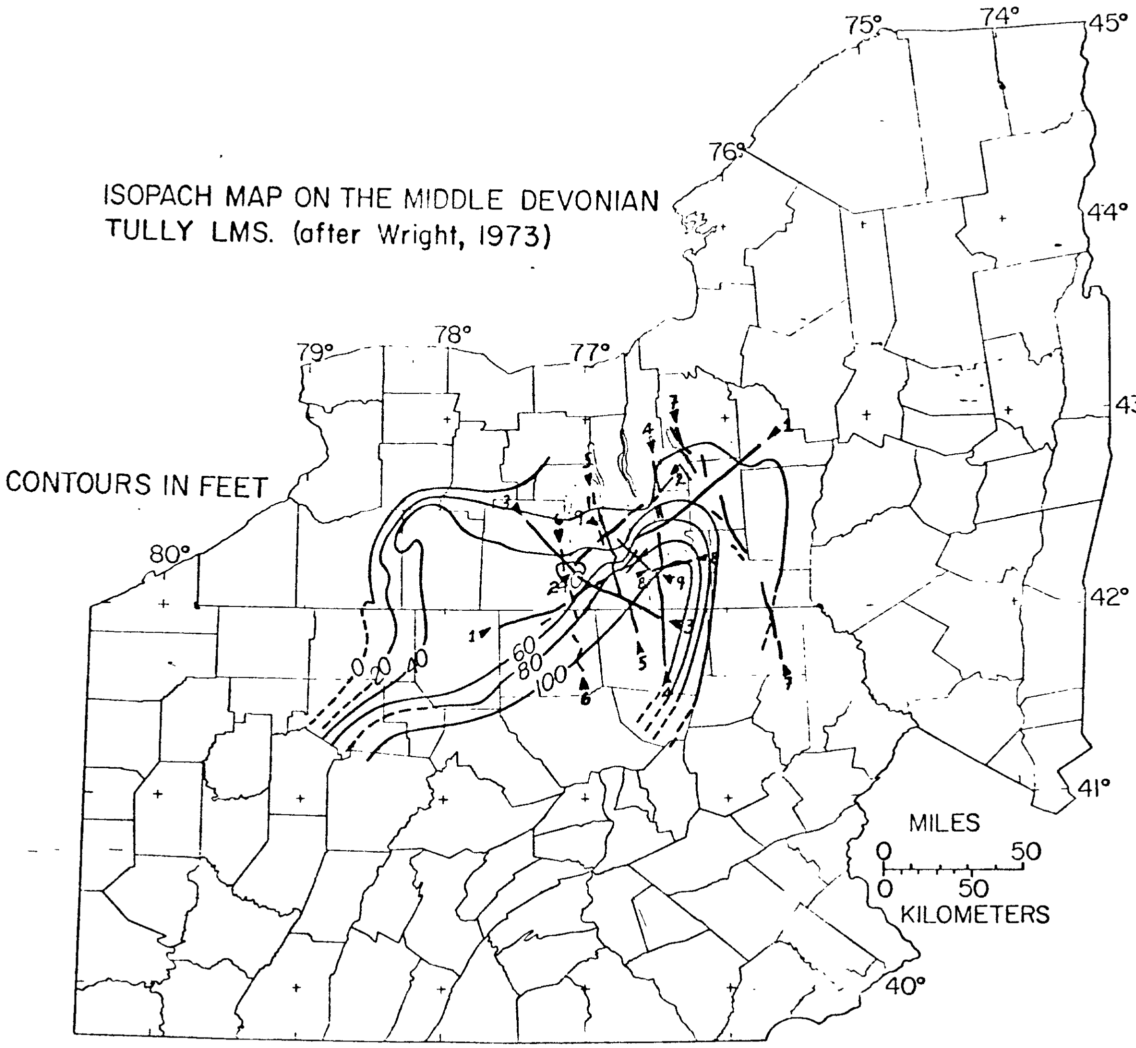

ISOPACH MAP ON THE MIDDLE DEVONIAN
TULLY LMS. (after Wright, 1973)
CONTOURS IN FEET
75°
74°
45°
76°
44°
79°
78°
77°
43°
80°
42°
41°
40°
0
20
40
60
80
100
MILES
0
50
0
50
KILOMETERS

Figure 19

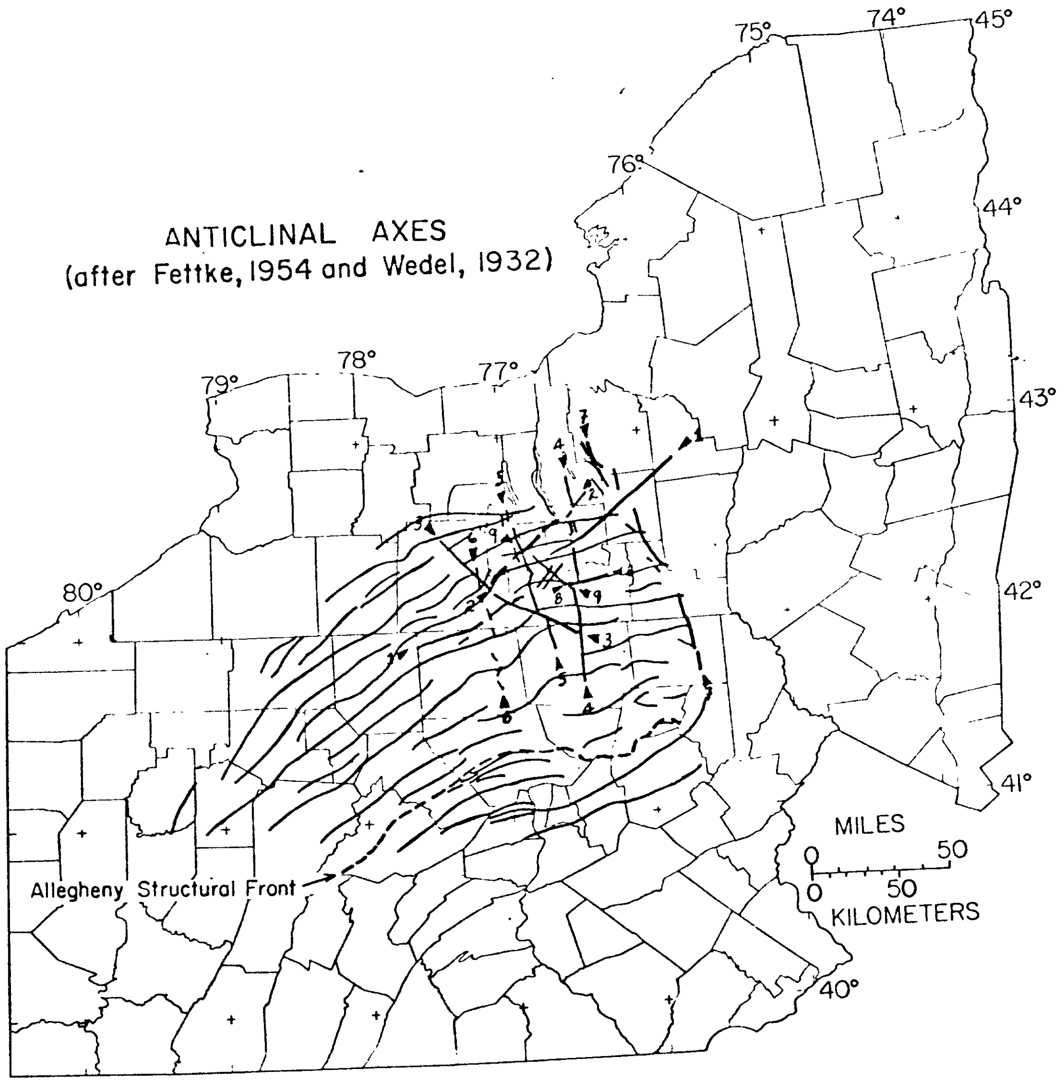

ANTICLINAL AXES
(after Fettke, 1954 and Wedel, 1932)
75°
74°
45°
76°
44°
43°
42°
41°
40°
79°
78°
77°
80°
MILES
0
50
0
50
KILOMETERS
Allegheny Structural Front

Figure 20

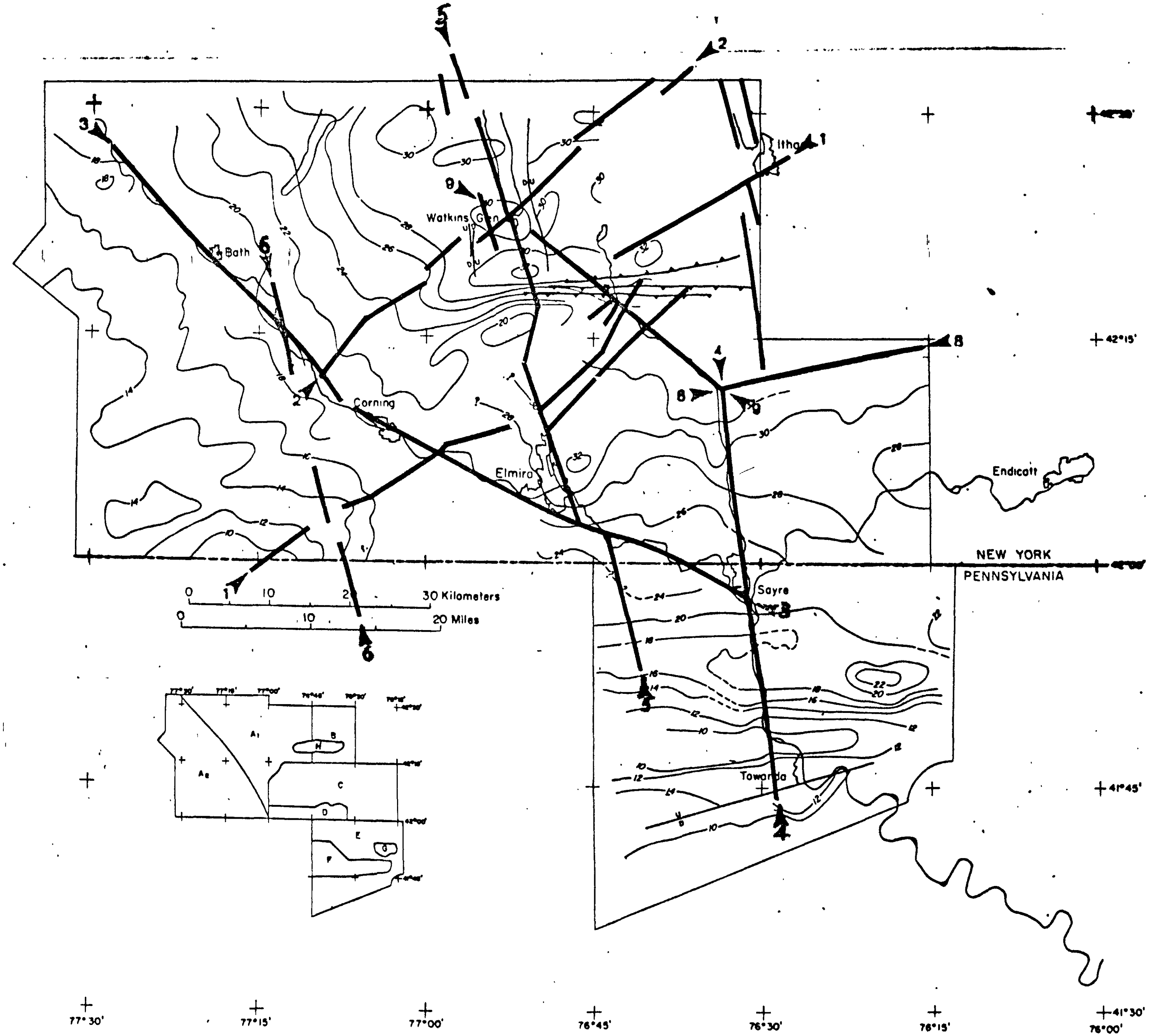

Ithaca
Watkins Glen
Bath
Corning
Elmira
Endicott
Sayre
Towanda
NEW YORK
PENNSYLVANIA
30 Kilometers
20 Miles
42°15'
41°45'
41°30'
77°30'
77°15'
77°00'
76°45'
76°30'
76°15'
76°00'

Figure 21

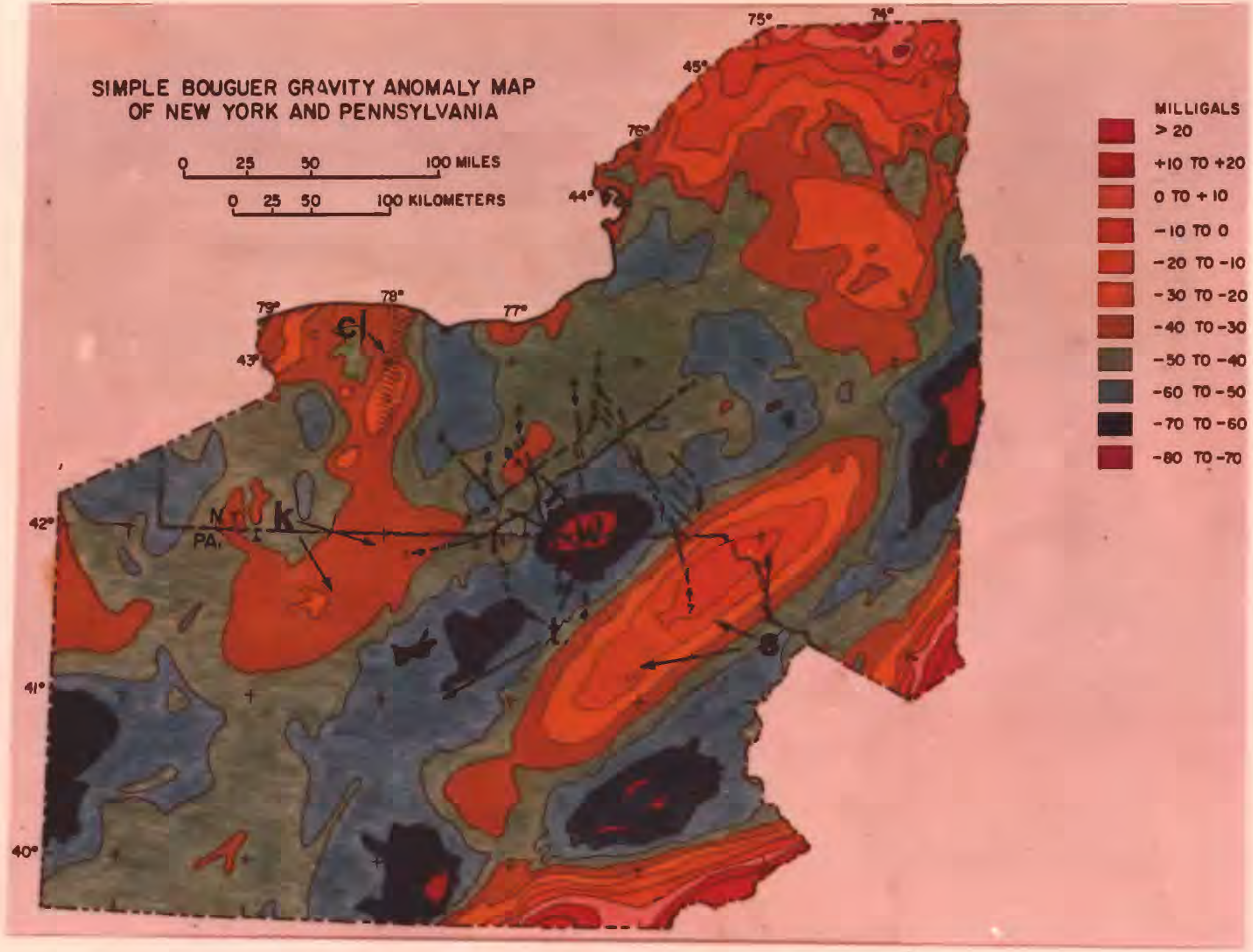

SIMPLE BOUGUER GRAVITY ANOMALY MAP
OF NEW YORK AND PENNSYLVANIA
0 25 50 100 MILES
0 25 50 100 KILOMETERS
MILLIGALS
> 20
+10 TO +20
0 TO + 10
-10 TO 0
-20 TO -10
-30 TO -20
-40 TO -30
-50 TO -40
-60 TO -50
-70 TO -60
-80 TO -70
75°
74°
45°
76°
44°
79°
78°
77°
43°
42°
41°
40°
N.Y.
PA.
K
Cl
W
S

Figure 22

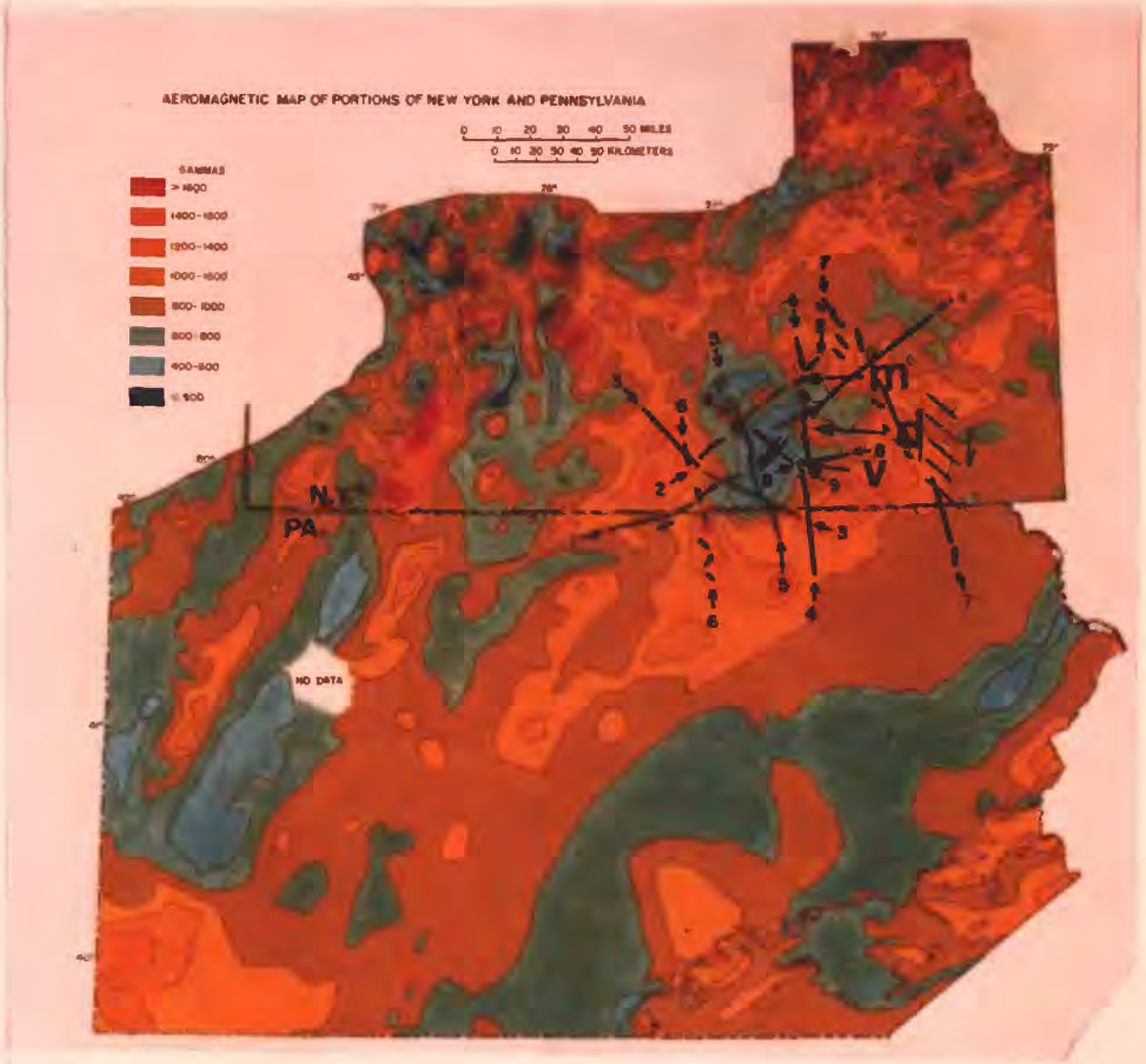

AEROMAGNETIC MAP OF PORTIONS OF NEW YORK AND PENNSYLVANIA
0 10 20 30 40 50 MILES
0 10 20 30 40 50 KILOMETERS
GAMMAS
> 1600
1400-1600
1200-1400
800-1000
400-600
N.Y.
PA
NO DATA

Figure 23

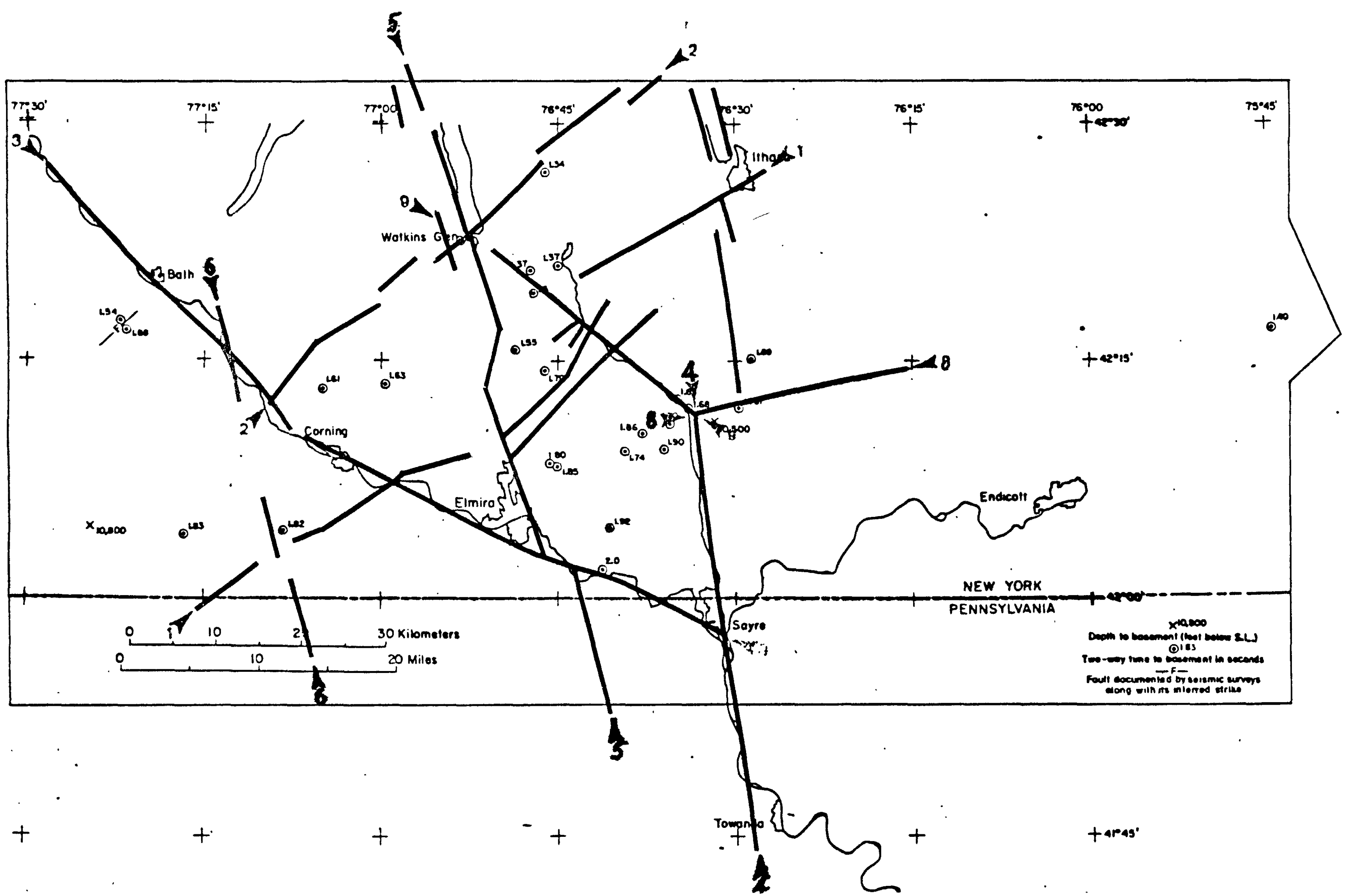

77°30'
77°15'
77°00'
76°45'
76°30'
76°15'
76°00
75°45'
42°30'
42°15'
42°00'
41°45'
Ithaca
Watkins Glen
Bath
Corning
Elmira
Endicott
Sayre
Towanda
NEW YORK
PENNSYLVANIA
0 10 20 30 Kilometers
0 10 20 Miles
X10,800
Depth to basement (feet below S.L.)
Two-way time to basement in seconds
Fault documented by seismic surveys along with its inferred strike

Figure 24

APPENDICES

Appendix B

THE RELATIONSHIP OF JOINTS AND STREAM DRAINAGE IN FLAT-LYING ROCKS OF SOUTH-CENTRAL NEW YORK AND NORTHERN PENNSYLVANIA

ABSTRACT

Examination of the relationship of joints to stream development shows that the oft-cited case of stream development parallel to joint directions does not, in general apply in south-central New York.

Streams whose courses are oblique to the joint directions (joint-oblique valleys) tend to erode easily due to increased corrasion and subsquent early undercutting at the upstream intersection of joints. The removal of joint-bounded blocks in joint-oblique valleys forms cascades which advance headward by apical erosion.

Streams whose courses are parallel and perpendicular (joint-parallel valleys) to the nearly orthogonal joint sets erode by a complicated mechanism of waterfall and plunge pool formation with headward undercutting of bedrock and subsequent collapse of unstable blocks into the plunge pools.

Most valleys in the Finger Lakes region are joint-oblique, although some well developed valleys are joint-parallel. These joint-parallel valleys are usually due to (1) a single deep, pervasive joint whose presence acts as a barrier to lateral expansion of the stream, or (2) erosion along joint zones whose intense fracturing produces weak erosional resistance in the rocks.

Previous Work on the Relationship of Joints to Stream Drainage

Several authors have written on the direct relationship between major joint directions and stream drainage. After studying the Finger Lakes region, it was Hobb's (1905, p. 367) opinion "beyond question that the joints have exercised an important control over the water courses". Sheldon (1912, p. 79), working adjacent to southern Cayuga Lake, stated that the "joint planes of this region have a marked influence on the forms of gorges, cliffs, and waterfalls." Cole (1930) illustrated the direct control by joints of the secondary deflection of the meanders in Coy Glen, N.Y.. Von Engeln (1961, p. 78), observed that the joint planes play a major role in determining the distinctive characteristics of upper portion of Enfield Gorge, N.Y.. Staheli (1971, p. 27), stated that the streams in the Elmira 1:250,000 quadrangle "follow very closely the joint trends of the area."

These authors and many others related drainage patterns in flat-lying or gently titled rocks to regional joint patterns. Although some valleys in south-central New York and adjacent northern Pennsylvania are indeed parallel to joint sets, the vast majority are not. In fact, this paper will show that in areas where erosion is primarily mechanical, downcutting can be more efficiently accomplished in valleys where the joint direction is oblique to the direction of stream flow. Consequently, the lineaments seen in satellite images are not generally parallel to joint directions.

Field Observations

The relationship between stream valleys and joint systems in the study area is best understood by examining the mechanism by which streams erode flat-lying, jointed rocks. The two mechanisms cited are representative of different stream development as a function of joint orientation.

There are two dominant, nearly orthogonal joint systems in the study area, and consequently, two geometric configurations with respect to streams are possible: (1) stream valleys that are essentially parallel to or perpendicular to a regional joint trend (joint-parallel valleys, fig. B-1a,b), and valleys that are oblique to the main joint directions (joint-oblique valleys, fig. B-2a, b). In both types of valleys, erosion is accomplished during peak flooding by grain plucking due to corrasion. Proportionally more grains are removed along joints than along bedding planes because of increased surface area. This type of erosion is common to both types of valleys whereas the remaining evolution of joint-parallel and joint-oblique valleys differ considerably.

In joint-parallel valleys, entire blocks are plucked out by flooding when the bounding joints are sufficiently deeply eroded (usually down to the subjacent bed). Removal of the block produces a small waterfall along the edge of the bed (fig. B-3). In order to remove the adjacent upstream block, the stream must go through the erosion process typical of a waterfall domain; floods must produce a plunge pool, the pool must erode in a headward direction until it undercuts the next headward block, and this undercutting must progress until the block will be free to tilt into the plunge pool (fig. B-4a). Following this evolution, the next flood will carry the block downstream where it may be ground into small particles and flushed from the system. In the study area, waterfalls are produced in virtually every case of joint-parallel valleys.

Clearly, lithology and stratigraphy must play a part in the formation of a caprock which will be resistant enough to allow undercutting of the block, and, in fact, in the study area (where alternating sequences of thin and thick bedded siltstones occur) most stream bed exposures show the major portion of the stream to be flowing on the thicker sequences.

In joint-oblique valleys, the notch formed by the intersection of joint planes is considerably different than the notch in joint-parallel valleys. Figure B-4b shows the relatively greater erosion at the joint intersections than along the joint faces themselves. The increased apical erosion of the blocks serves to undermine the headward point of the block (fig. B-4b) so it can be plucked out under less exteme hydraulic conditions than the joint-parallel block. Removal of blocks in this situation almost always produces a cascade rather than a waterfall (fig. B-5). The cascade has a very different evolution than the waterfall, because the erosion of the subjacent joint begins as soon as the apex of the superjacent block is undercut. The subjacent block is in turn subject to removal as soon as the joint intersection is sufficiently eroded to produce undercutting on the upstream side. The formation of plunge pools, headward erosion, and undercutting on the downstream side is unnecessary for removal of blocks in joint-oblique valleys. In this manner, the bedrock-based valleys in the study area whose joints are oblique to the valley direction are, by far, the most easily eroded.

A second type of erosion common in the study area is the tilting of whole joint bounded blocks due to ice or frost wedging. Joint-oblique blocks, having greater available space under the upstream apex will tend to be filled with water and loosened or tilted more readily by the formation of ice wedges, and hence, will be more easily eroded in spring floods than joint-parallel blocks.

Most of the valleys cited in the previously mentioned literature are joint-parallel, and, in fact, there are a small number of spectacular joint-parallel valleys in the region of the Finger Lakes. There are two explanations as to why these valleys occur. First is the presence of a single vertically pervasive joint, which may extend downwards for tens of meters. During the process of downcutting, the joint that is parallel to the incipient stream acts to check lateral erosion. As erosion progresses vertically or laterally, the moving water is stopped at the joint face and a vertical wall is excavated by the stream. If two vertically pervasive joints occur within several meters (or tens of meters), both joints will act as barrier walls and will trap the stream in a flume between them. The result can be conspicuous valley with nearly straight sides.

The second and more common situation is where a joint zone or several joint zones are present in the region of the incipient stream valley. In this instance, a random change in the stream course will eventually intersect one of the joint zones. The closely spaced orthogonal fractures of the joint zone lower the bedrock coherence and hence facilitate rapid erosion. Individual blocks are easily removed from the joint zone during periods of flooding. If two or more joint zones lie within the stream valley, the zones will eventually control both sides of the stream and will delineate large segments of the stream valley.

The mechanical evolution of a stream trapped between a joint zone is illustrated in figure B-6. This example is taken from an exposure along Olcott Creek, located along the Steuben-Chemung County line in the Big Flats, NY 7 1/2 minute quadrangle. Several tens of meters upstream, the stream enters the present area of joint zones from the northeast. The stream flows against the westernmost joint zone and is deflected to the east. It encounters the central joint zone. From that point downstream for approximately 100 meters, the water is trapped between the two joint zones until the stream breaks over the west-central zone at a waterfall and is deflected back to the west by the easternmost joint zone. The stream is bound by the east-central and easternmost zones for several hundred meters. The overall course of the stream is N10° - 15° E, as is the strike of the joint zones. The two major regional joint sets at this outcrop, strike N30°W and N62°E, but the valley does not follow either trend; instead it is a product of a joint zone which does not follow the regional joint sets.

Field Studies

Introduction

The joint systems in the Finger Lakes area of New York have been studied since the 1890's when geologists first observed that the trends of some of the stream and lake valleys are essentially parallel to the strike of the major joints. Hobbs (1905) was among the earliest workers to study the joint patterns in the region and concluded that the joint system had exercised an important control on development of the stream pattern. He pointed out (1905, p. 367), that in the Finger Lakes region the joints constituted a "major system" consisting of joint sets striking N, N45^{o}W, and N70^{o}E, and a "minor system" which included joint sets between N and N20^{o}E, and N70^{o}W. Sheldon (1912) showed that the major and minor joints in the Ithaca area strike nearly parallel and perpendicular to the axes of the local folds.

Parker (1942) made the first systematic study of the joints in south-central New York as part of a statewide study of the regional joint patterns. He concluded that the joints in the area could be divided into three distinct sets: Set I trending N-S, Set II trending east-west, and Set III striking N59E. Parker observed that the orientation of the first two sets gradually rotated anticlockwise from the Catskill Mountains on the east to Elmira, New York on the west. He further observed that Set I was composed of two joints which represent "two conjugate shears intersecting at very acute angles (averaging 19^{o})" (Parker, 1942, p. 382). Nickelson and Hough (1967), mapping in northern Pennsylvania, noted a discrepancy between their data and that of Parker. They believed that Parker's Set I joints corresponded to three of their joint sets, and that the double nature of Parker's Set I joints could be explained by an "overprinting" of differently oriented joints from adjacent areas in which only one set predominates, (Nickelson and Hough, 1967, p. 622). A further confrontation in print occurred in 1969 between these authors (Parker, 1969; Nickelsen and Hough, 1969) which failed to resolve the dispute.

Measurements

The observed relationships between joint orientation and stream development indicated the need for a systematic study of the orientations of the joints and the lineaments mapped from Landsat images. Data compiled by earlier workers was not used because it was not used because it was not clear from the literature how many joint sets were present or how these joint sets varied regionally.

Because we thought that the geographic coverage between and among quadrangles might be responsible for the discrepancies between Parker (1969) and Nickelson and Hough (1969), we devised our own sampling program to optimize the useful information in each quadrangle. First we recognized the need for all quadrangles to be contiguous to prevent over-looking an abrupt shift in the joint patterns produced by unmapped faults or flexures in the low amplitude folds. Next, we attempted to locate as many outcrops as possible by driving every road and examining all the valleys which showed potential for bedrock exposure. After all the available outcrops were located on individual

7-1/2 minute quadrangle maps, we selected twenty to thirty outcrops which would yield the optimum geographic coverage for each quadrangle. The outcrops were then revisited and joint measurement obtained.

Our method of recording joints at the individual outcrops differed from those methods used by previous workers in that, instead of measuring every joint observed at an outcrop, we measured a single joint whose strike was observed to be representative of a joint set present in the particular outcrop. Minimum and maximum spacing of joint sets were were also recorded. A joint which deviated more than a few degrees from the main directions was recorded separately. The presence of single joints not related to a set, or of joint zones, where related to sets or not, was also recorded. Joint sets were entered in order of diminishing prominence (horizontal continuity, vertical pervasiveness and closeness of spacing) for each outcrop, so we were aware of possible duplication of joint sets as we moved along an outcrop containing hundreds or thousands of joints.

The technique yielded an average of twenty-two outcrops and approximately 100 actual measurements (effectively representing 200-300 joints) for each 7-1/2 minute quadrangle.

Plotting

In plotting the joints, we felt that traditional techniques of using rose diagrams failed to maximize the display of joint sets separated by only a few degrees and to give sufficiently visible contrast to the individual quadrangles. For these reasons, we chose to plot the joints as histograms and to arrange the histograms in a vertical stack representing the quadrangles from west to east.

Some authors have advocated the use of class intervals which are larger than the probable magnitude of error contained in the data (Abdel-Rahman and Hay, 1978). We felt that the accuracy of measuring the joints would be no better than two or three degrees because of the deviation from planarity of the joint surfaces. Thus the joint measurements would form a random Gaussian distribution about the true strike. For this reason, we chose to portray the joints in class intervals of one degree.

The trends of joints were measured in ten contiguous 7-1/2 minute quadrangles from Maine, New York to Campbell, New York (fig. B-7). The northwesterly striking joints (fig. B-8a and b), are part of a set that gradually changes strike first described by Parker (1942). The joints immediately to the east of this set are part of Parker's double set of "two congugate shears intersecting at very acute angles (averaging 19°)" (Parker 1942, p. 382). The northeasterly trending joints (Parker's Set II) can also be seen to change gradually from west to east across the study area. This second set may also be doubled, but data are insufficient to prove this.

We do not observe the presence of Parker's Set III which he stated "shows a remarkably constant strike across the whole area, averaging N59°E" (Parker 1942, p. 338). We have not noticed the presence of this latter set even in the West Danby 7-1/2 minute quadrangle (fig. B-9). This quadrangle is located in the southeast quarter of the Ithaca 15 minute quadrangle where Parker noted that his Set III "attains a prominence equalling or even exceeding that of Set I." (Parker 1942, p. 388). Significantly, Nickelson and Hough also fail to find this set in Pennsylvania. We feel that the prominence of this apparently spurious joint set in Parker's data might be due to his tendency to concentrate his measurements on a few outcrops. We avoided the problem in our study by maximizing the geographic distribution of measurements and by minimizing the reliance on a single outcrop.

Mapping joints in an eleventh quadrangle in the Maine-Campbell tier has recently been completed. The joint distribution in the Rathbone quadrangle (immediately to the west of the Campbell quadrangle) is shown in figure B-10. The northwest trending joint set is shifted ten to twenty degrees eastward with respect to the Campbell quadrangle. The Rathbone quadrangle is the first quadrangle located entirely to the west of the thick Upper Silurian salt sequence (fig. 17, main text of this study).

Conclusions

Parker (1942) was essentially correct in his appraisal that his Set I joints change orientation gradually from east to west in New York State. This is incompatible with the fact that Nickelson and Hough (1967) find three distinct, but slightly overlapping, northwesterly trending joint sets in Pennsylvania. One possible explanation for this apparent change in joint trends is a detachment zone between the two study areas which might be due to a change in structural style. To this end, we extended our field investigations into northern Pennsylvania and mapped joints in contiguous quadrangles between the two study areas. Parker's Set I and II joints are present in Pennsylvania and show the continual rotation in strike from east to west that he observed in New York.

REFERENCES CITED

Abdel-Rahman, M. A. and Hay, A. M., 1978, Statistical analysis of multi-model orientation data: Third Ann. Basement Tectonics Sympos., Durango, Colorado (in press).

Cole, W. S., 1930, The interpretation of Intrenched Meanders: Jour. of Geol., v. 38, p. 423-236.

Hobbs, W. H., 1905, Examples of joint-controlled drainage from Wisconsin and New York: Jour. of Geol., v. 13, p. 363-374.

Nickelsen, R. P. and Hough, V. D., 1967, Jointing in the Appalachian Plateau of Pennsylvania: Geol. Soc. Amer. Bull., v. 78, p. 609-630.

Nickelsen, R. P., and Hough, V. D., 1969, Jointing in south-central New York: Reply, Geol. Soc. Amer. Bull., v. 80, p. 923-926.

Parker, J. M., 1942, Regional systematic jointing in slightly deformed sedimentary rocks: Geol. Soc. Amer. Bull., v. 53, p. 381-408.

Parker, J. M., 1969, Jointing in south-central New York: Discussion Geol. Soc. Amer. Bull., v. 80, p. 919-922.

Sheldon, Pearl, 1912, Some observations and experiments on joint planes: Jour. of Geol., v. 20, p. 53-79.

Staheli, A. C., 1971, Topgraphic criteria for recognition of a threshold of erosion by the Laurentide ice sheet, unpublished PhD thesis, U. of North Carolina at Chapel Hill, 82p.

Von Engeln, O. D., 1961, The Finger Lakes Region: Its Origin and Nature (1st edit.): New York, Cornell Univ. Press, 156 p.

Figures for Appendix B

B 1a Schematic diagram of a joint-parallel valley - Spacing between joints has been slightly expanded to show the rounding of corners at joint intersections.

B 1b Cross-Section A-A' showing the slight increase in erosion at the upstream edge of the joint-bounded blocks. Arrows show direction of water movement.

B 2a Schematic diagram of a joint-oblique valley. Spacing between joints has been expanded slightly to show the increased erosion at upstream apices.

B 2b Cross-section B-B' showing the separation of blocks along joint boundaries.

B 3 Typical joint-parallel valley showing the development of a waterfall. As the stream erodes headward, the waterfall retreats along a front perpendicular to the stream flow.

B 4a,b Comparison of joint-parallel and joint-oblique cross-sections. Figures are referenced in sequence from top to bottom. a1 - initial configuration; a2 - plunge pool begins to form; a3 - plunge pool deepens and undercutting begins; a4 - block is just about to become unstable; a5 - block tilts into plunge pool. The next episode of major flooding will carry the block out of the scene. b1 - Apical erosion has already separated the block from the adjacent upstream block; b2 - undercutting advances; and b3 - the block is being carried away.

B 5 Joint-oblique valley showing a typical development of a cascade. Note the block which has been removed from the middle of the stream. Any block in the stream bed can be removed at any time.

B 6 Schematic diagram of a portion of Olcott Creek. Joint zones are oriented N10^{o} - 15^{o}E. Stream enters at east side, is deflected by westernmost joint zone and is entrenched between joint zones. In the middle distance, the stream breaks across the west-central joint zone and forms a waterfall. Downstream the channel is formed by two other joint zones.

B 7 Index map of New York showing the ten contiguous quadrangles mapped for the preliminary joint study.

B 8a Azimuth-frequency histograms of the ten quadrangles mapped for the preliminary joint study. The smallest vertical bars represent one joint measurement.

b Map of the mean of each of the two joint directions in each of the quadrangles. wd-West Danby, cb-Campbell, co-Corning, bf-Big Flats, hh-Horseheads, er-Erin, ve-Van Etten, sp-Spencer, cn-Candor, nk-Newark, mn-Maine, sr-Sayre, ut-Ulster.

B 9 Azimuth-frequency histogram of the West Danby quadrangle joint measurements. Note that the increased joint frequency from N60E to EW is part of the northwest joint set.

B 10 Azimuth-frequency histogram of the Rathbone quadrangle joint measurements. There has been an abrupt shift eastward of the northwest joint set relative to the adjacent Campbell quadrangle.

Figure B-1a

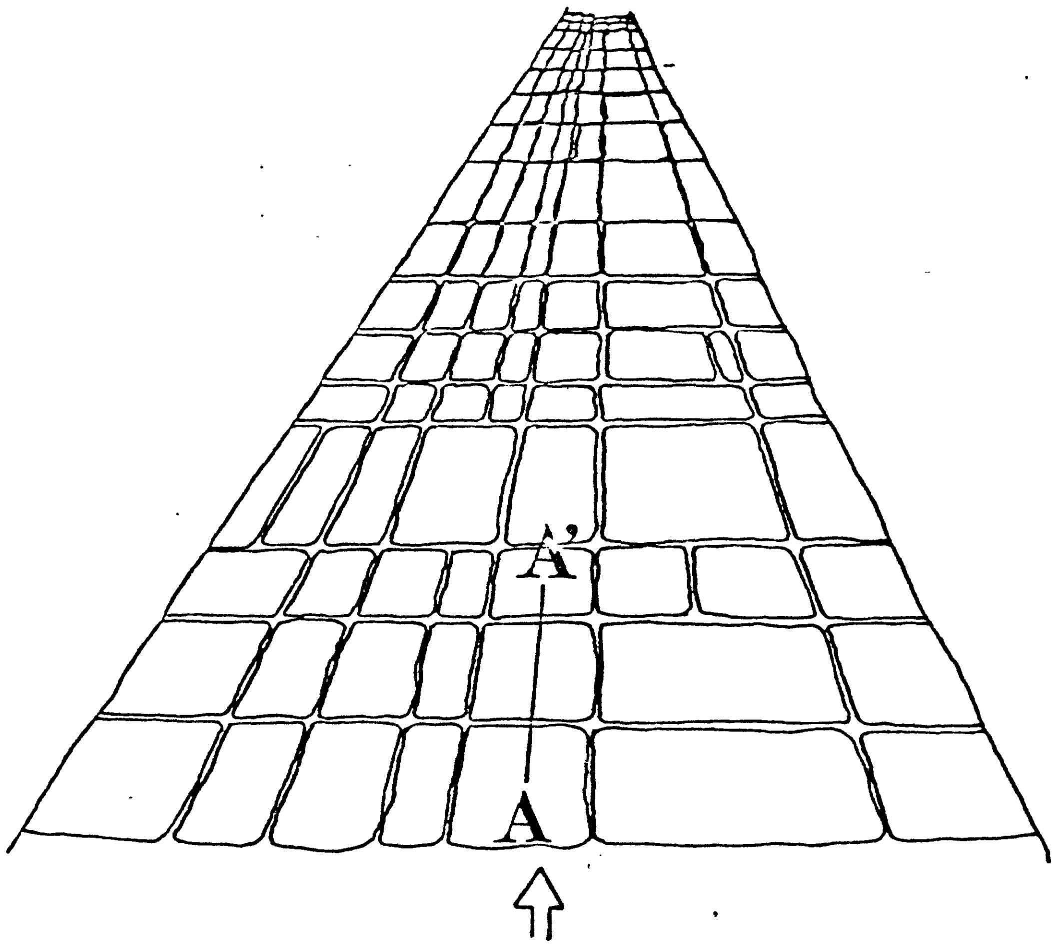
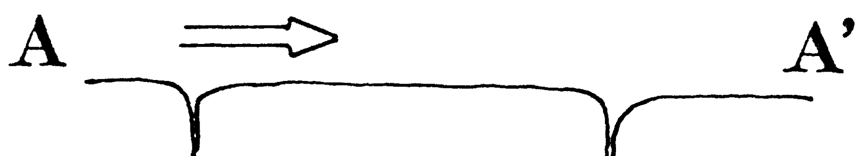


Figure B-1b



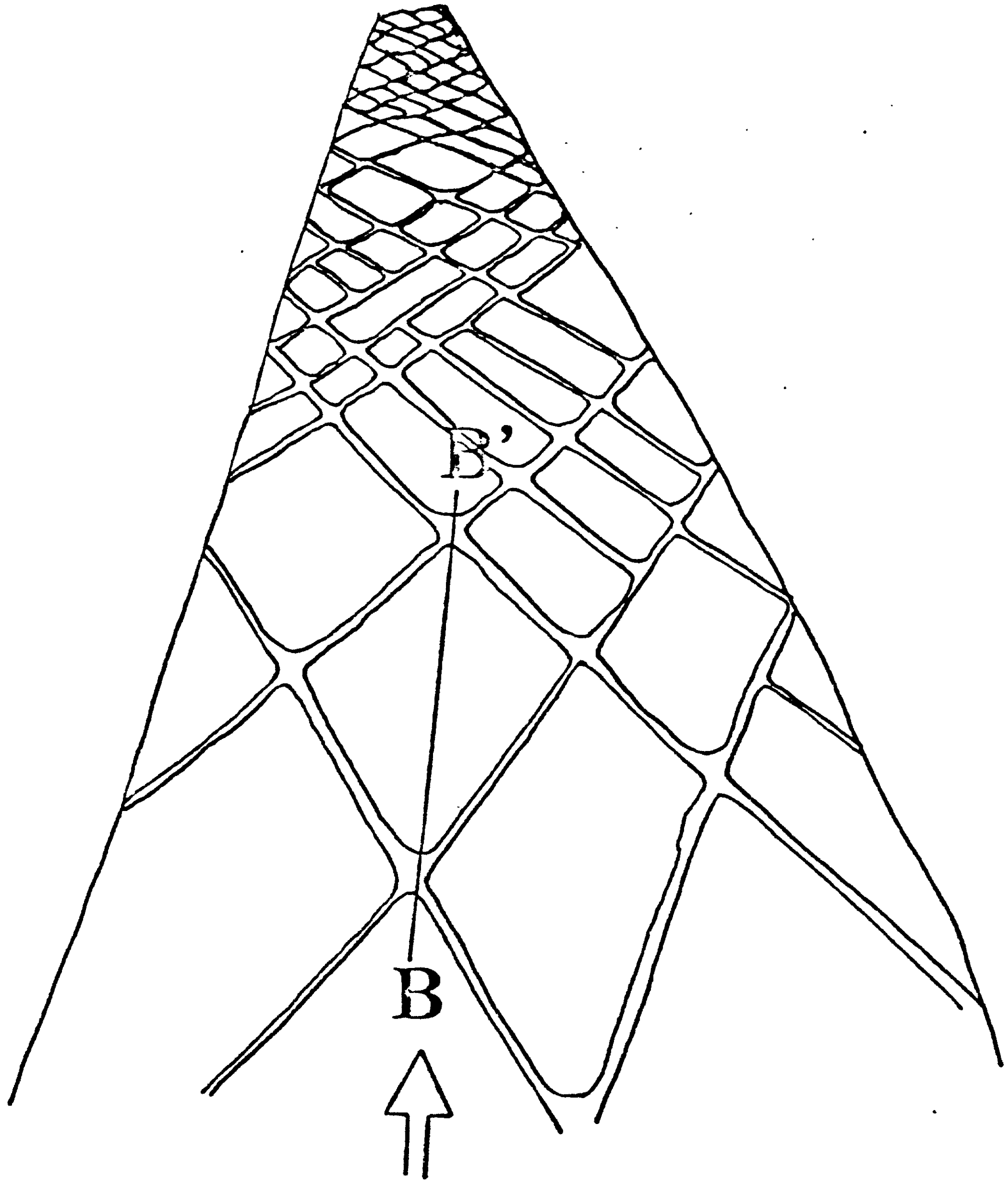


Figure B-2a

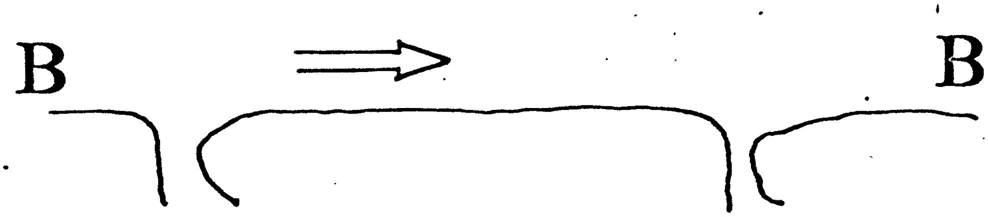
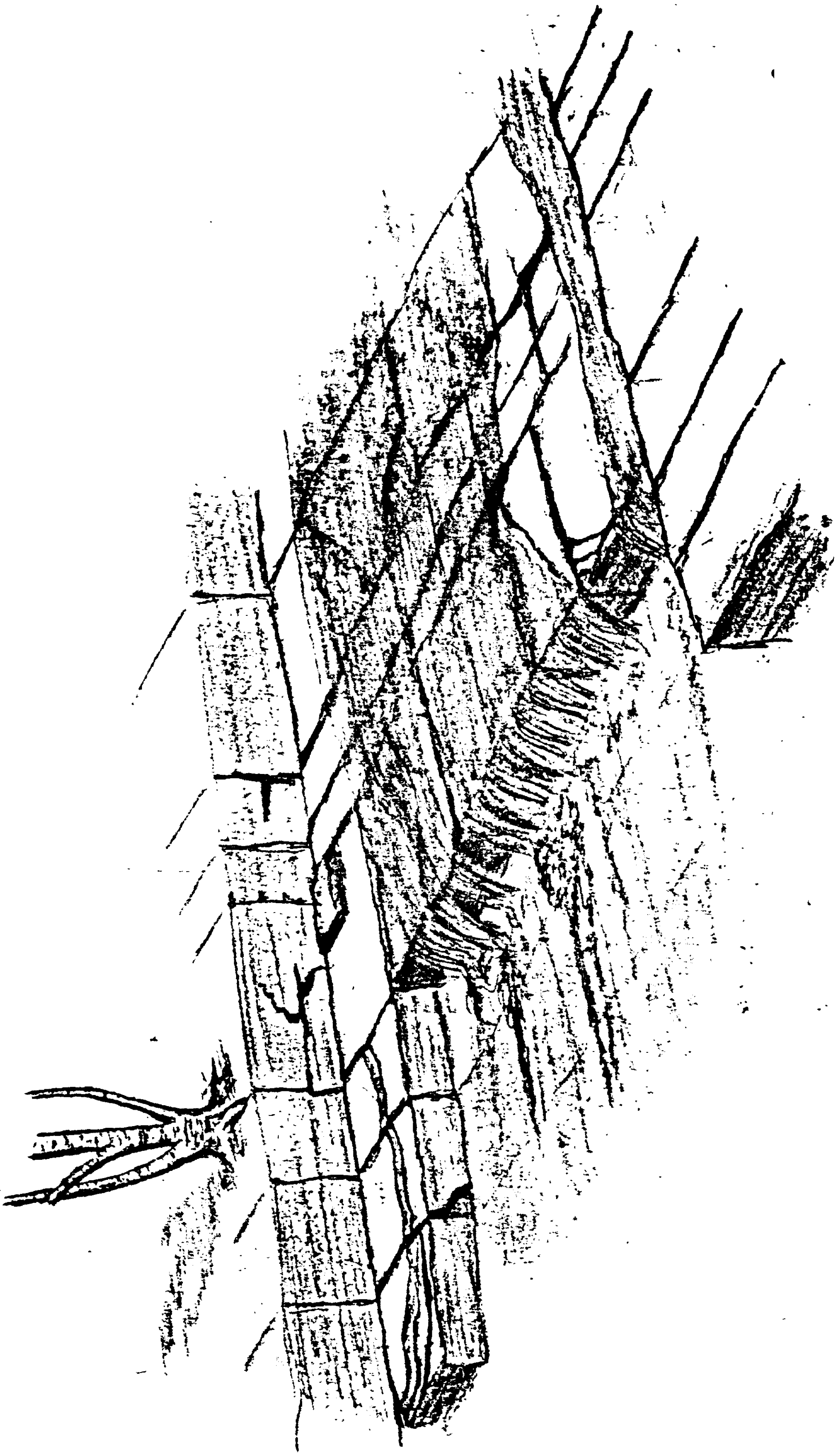


Figure B-2b



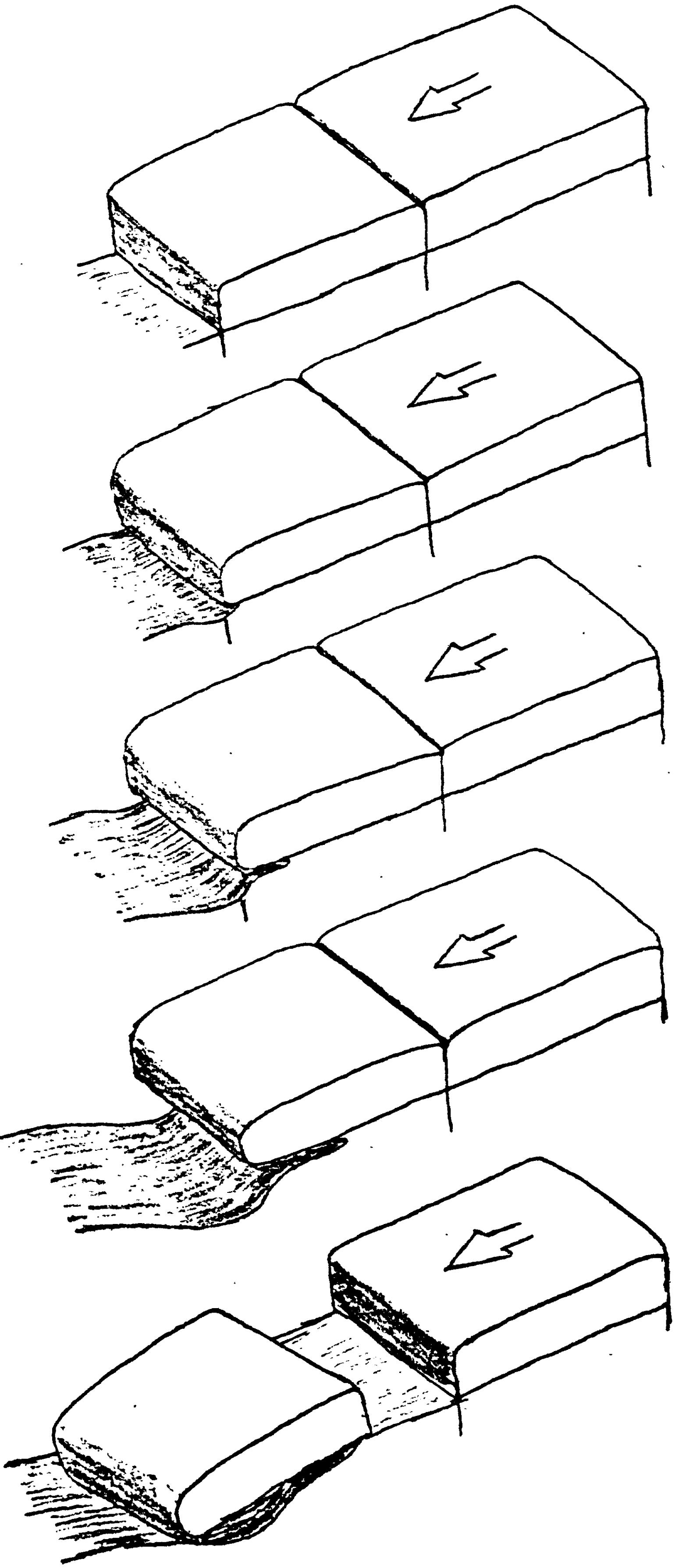


Figure B-4a

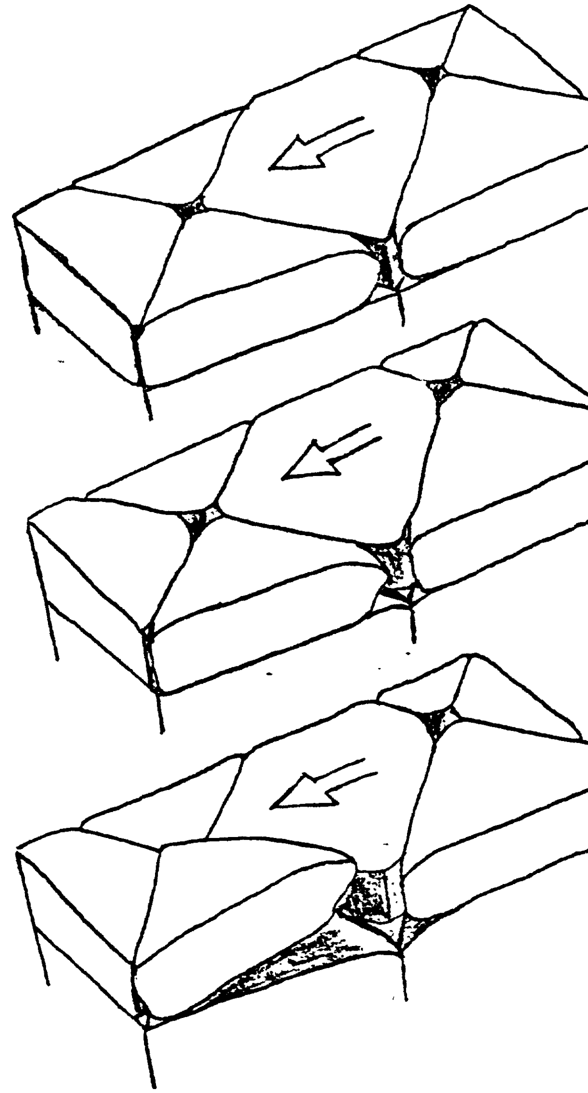


Figure B-4b

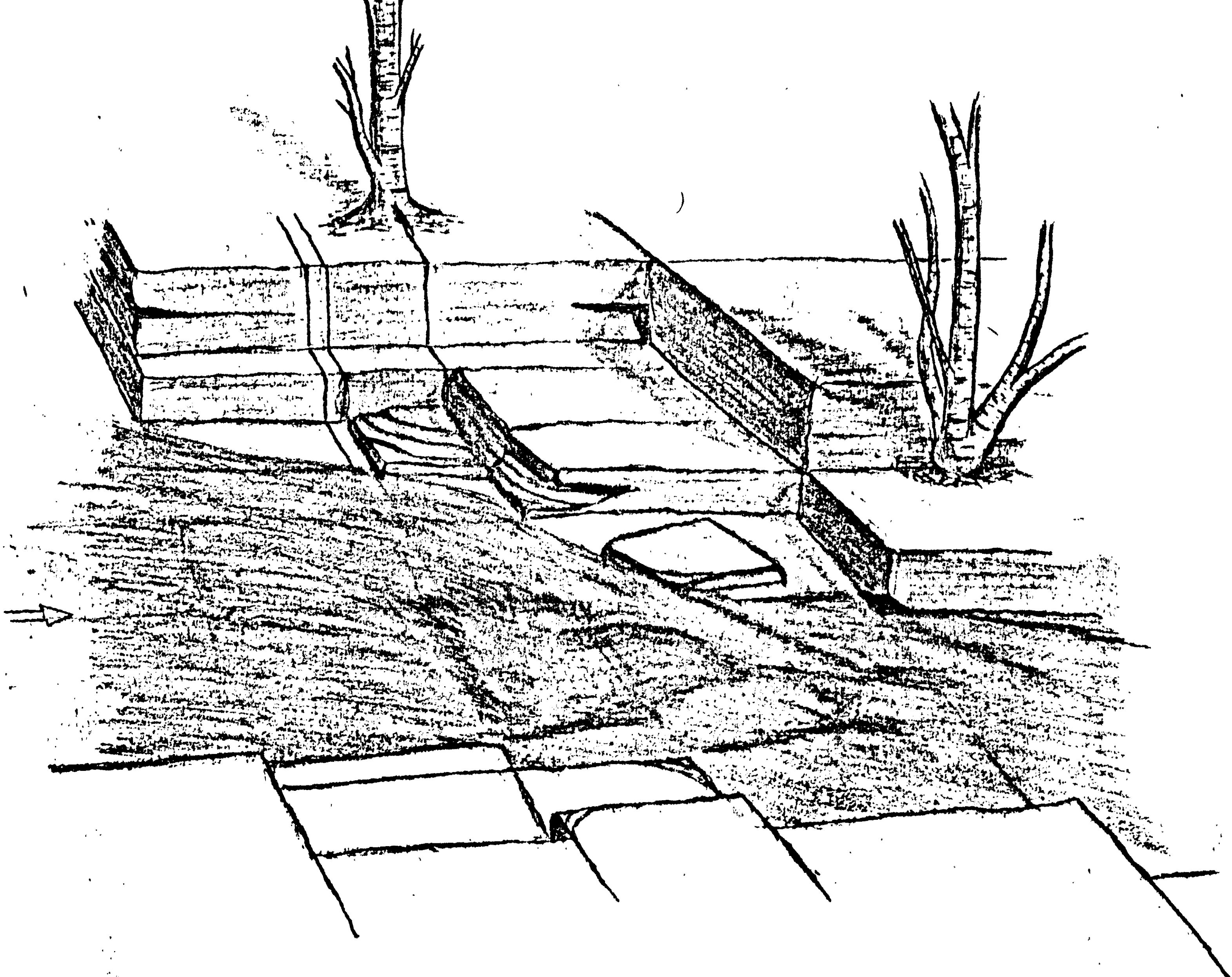


Figure B-5

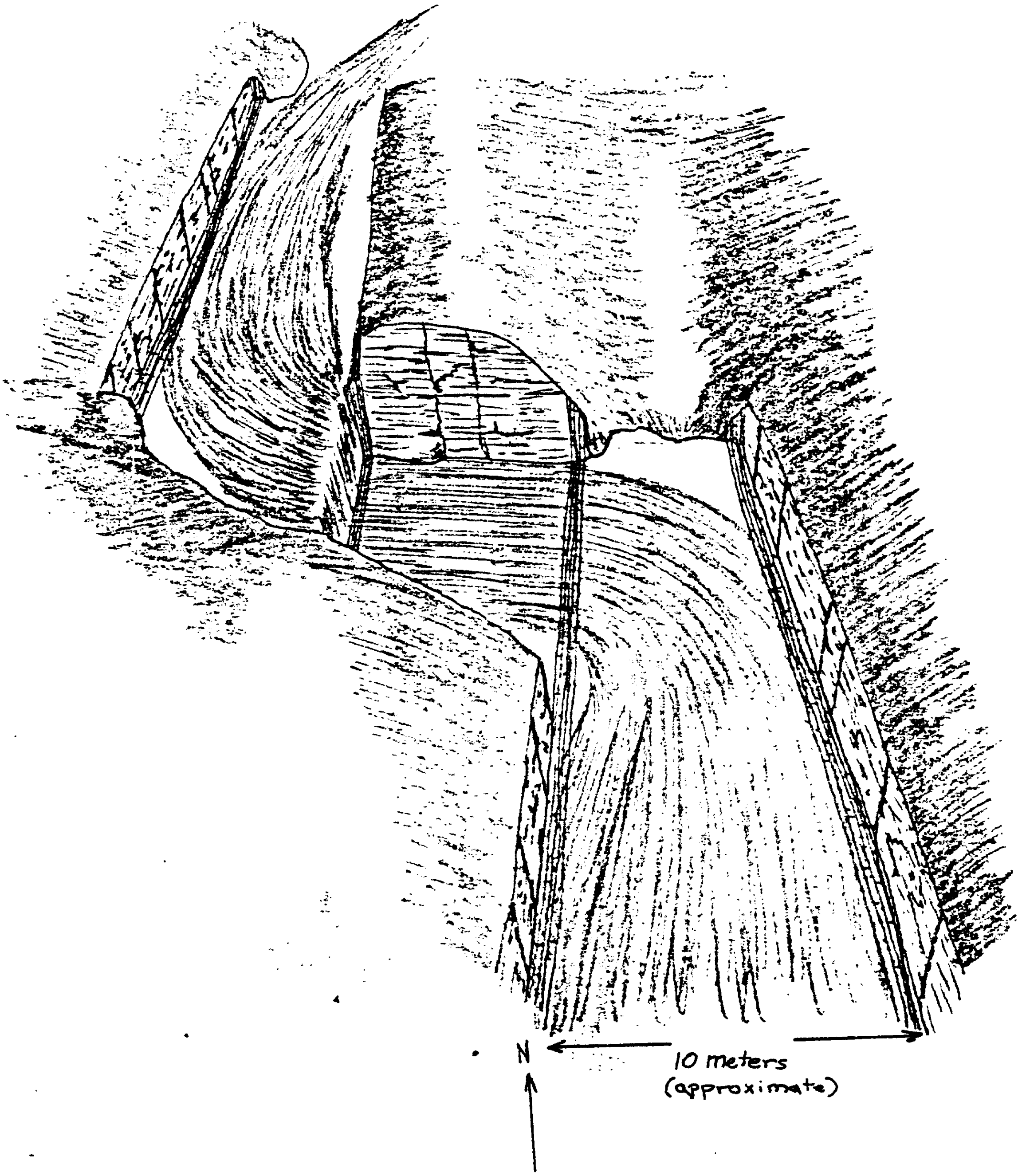


Figure B-6

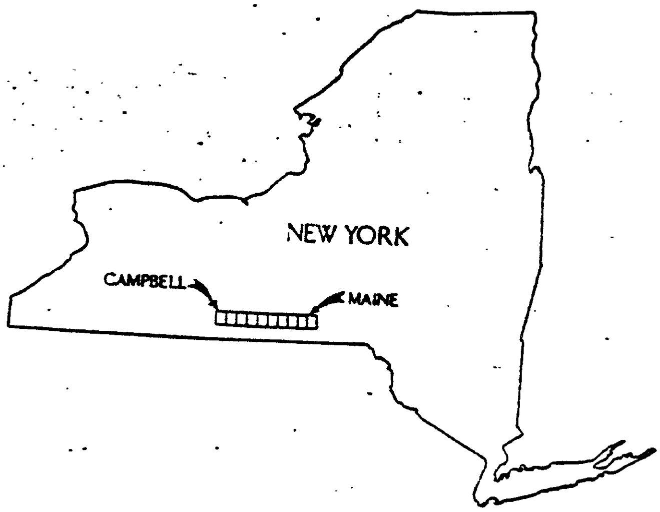


Figure B-7

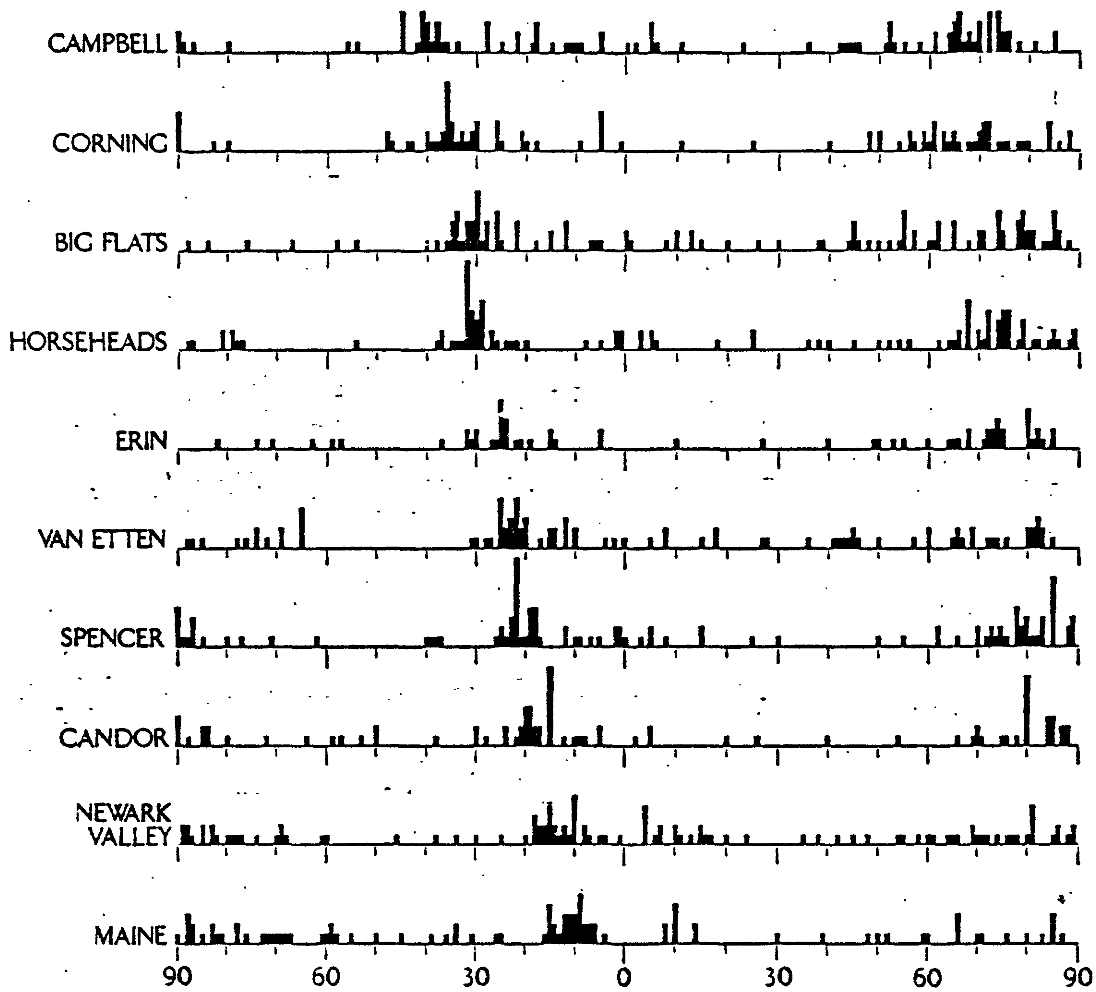


Figure B-8a

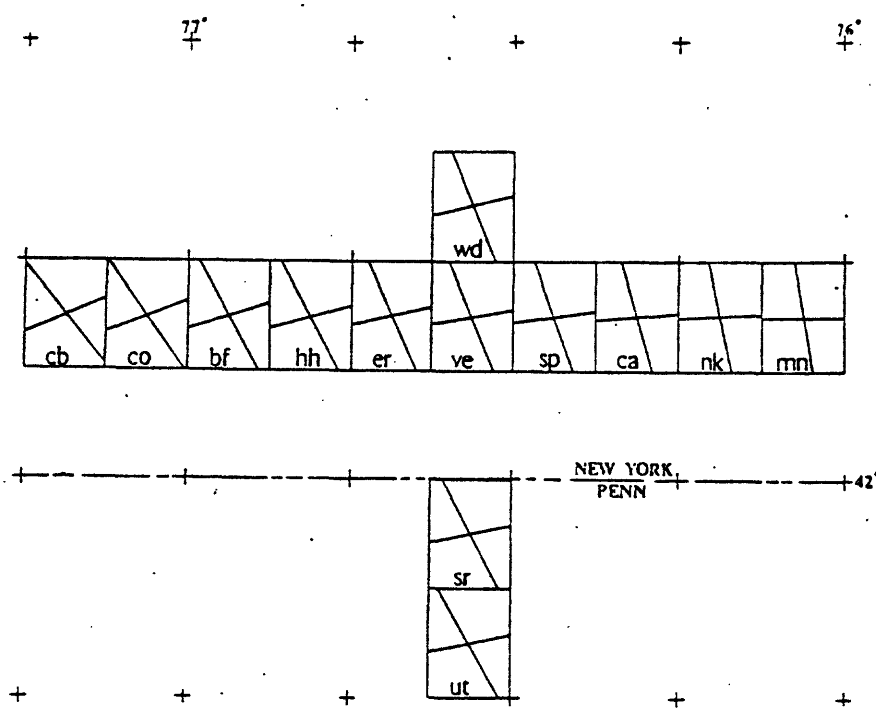


Figure B-

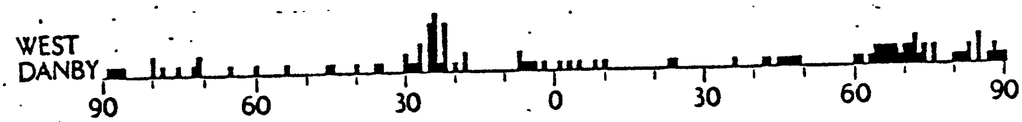


Figure B-9

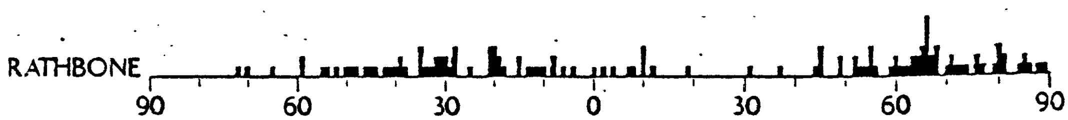


Figure B-10

Appendix C: Statistical Analysis of Lineament Data

The 506 lineaments (fig. C1) delineated on the MSS photomosaic (fig. 2a, main text) of the broader region were digitized and recorded on computer-compatible tape to facilitate statistical analysis using the LINANL programs (Sawatzky and Raines, in press). The analysis is incomplete because of the premature termination of the study. The purpose of this procedure is to identify statistically significant trends by systematic analysis of frequency-azimuth histograms. The analysis may be done using either frequency (number of lineaments per azimuth class) or by length-weighting of the frequency distribution (total length of lineaments per azimuth class). Length-weighted distributions of lineaments are evaluated in this study because they tend to emphasize long lineaments which appear to be structurally more important than short lineaments.

The length-weighted frequency distribution of the 506 lineaments is characterized by numerous peaks and troughs that are significant deviations from a random uniform distribution (fig. C2, Table C1). The procedure used to identify the peaks and troughs is heuristic, so that the term "significant" is not used in the true statistical sense (Sawatzky and Raines, in press).

The troughs in the length-weighted distribution (fig. C2, Table C1) were used to identify the azimuthal extent of the significant peaks. By this means, a range of significant peaks separated by non-significant peaks are considered to constitute a single trend bounded by significant troughs.

TABLE C1

Range of significant azimuthal peaks and troughs (at 0.999) in the length weighted frequency azimuth distributions of lineaments

Troughs	Peaks	Composite Trends	Peak or Trough**	
270-306*	307-309		T1	
310	311-318	307-330	P1	(69)
319-321	322-330			
341	335-339			
		334-357	P2	(85)
358-2	342-357			
6-10	3-5			
22	11-19	11-20	P3a	(34)
46	24-45			
		20-48	P3b	(11)
49	47			
54	49-53			
61	55-60	49-66	P3c	(62)
67-72	62-66			
	72-79	72-79	P4	(17)
80-90*		270-306; 80-90	T1	(57)

* 270-306 and 80-90 form one composite trough.

** Numbers in parentheses indicate number of linear features composing this trend.

Several significant ranges of azimuth were segregated from the total distribution of lineaments using this technique (fig. C2, Table C1). Numerous significant peaks with widths of only a few degrees were found throughout the histogram. When these narrow azimuth ranges were used to generate plots of the areal distributions for the individual lineament peaks, no readily recognizable patterns were apparent; rather, the few lineaments appeared to be randomly distributed over the map area.

As can be seen from figure C2, no sharp peaks in the azimuthal trends are readily descernible from the frequency-azimuth histogram. Rather, the histogram shows a broad continuum of azimuths with relatively high length-weighted frequency values. This lack of a sharp pattern may be due to one or more factors. The broad peaks may relate to mixed subpopulations of lineaments (i.e. mixing of lineament patterns from several differing geologic subprovinces) each differing from the other by only several degrees in their peaks. Alternatively, a broad azimuthal trend may be formed by a subtle shift in azimuthal trend across the area. Whichever of the factors may be correct, examination of the Landsat mosaic (fig. 2a - main text) and the lineament pattern derived from it suggests that the probable causes of the broad peaks may be related to several geologic processes.

First, the area has undergone several episodes of glaciation during the Pleistocene. One major ice advance proceeded southward from the Lake Ontario basin and encountered the Onondaga Escarpment, located approximately at the north end of the major Finger Lakes such as Skaneateles, Cayuga, Seneca and Canandaigua. The escarpment forms an arcuate barrier, concave to the north, and essentially defines the Lake Ontario topographic basin. The glacial advance was impeded in its southward progress by the escarpment until sufficient ice accumulated to override the barrier. Upon topping the barrier the ice advance proceeded radially outward from the basin over the uplands of the Finger Lakes area. The radial dispersement of the ice may account for the shift of the northwesterly lineaments from approximately N25^{o}W at Endicott, NY to N10^{o}W at Elmira, NY.

Second, the lineaments may reflect the gradual change in trend of the Ridge and Valley and Allegheny Plateau physiographic province. In the vicinity of Williamsport, PA (W, fig. 2a - main text) the strike of the Ridge and Valley province is approximately N70^{o}E. Williamsport marks the approximate easterly extent of a salient in the Appalachians which protrudes west to northwest into the continental foreland of the U.S. (Central Appalachian Salient of Rodgers (1970)). East of Williamsport, the Appalachians form a recess which begins to swing north, ultimately to an azimuth of about N35^{o}E at the common border point of New York, Pennsylvania and New Jersey. This change in strike can be readily seen in the arcuate trend of the Lackawanna Syncline (L, fig. 2a - main text).

We believe the swing of the northwesterly lineament trends may be structurally related to the change in strike of the Appalachian fold belt. If the structural control hypothesis is correct, the weak zones most likely predate the Pleistocene. Thus maximum glacial erosion preferentially may have followed those previously existing structural features oriented parallel to the ice direction, further enhancing physiographic character of the lineaments.

Sun illumination angle may have introduced a possible bias into the lineament pattern. Lineaments parallel to the direction of illumination may not be as readily apparent on the images as those at some large angle to the sun's rays (Wise, 1969). Thus, those lineaments parallel or nearly so to the sun's rays would be underrepresented, whereas those normal to the sun's illumination would be relatively overrepresented. The images used in the mosaic (figs. 2a and b - main text) have average illumination azimuths of 152^o for the October images and 140^o for the March images. Consequently, those lineaments striking in the general directions of 332^o (N28^{o}W) and 320^o (N40^{o}W) may be underemphasized. Indeed, both of these directions are significant troughs in the frequency-azimuth distribution (fig. C2 and Table C1).

The significant peaks were combined into broader peaks, using the broader significant troughs in the frequency-azimuth distributions as boundaries. Narrow troughs of 1 to 2 degrees were generally ignored. The composite peaks are also shown in figure C2 and Table C1.

Examination of the aggregated 307^o-330^o peak (P1, fig. C2 and Table C1) shows the lineaments fall into two broad regional groups separated by a nearly empty meridional swath centered at 77^{o}W (fig. C3). Several major lineaments of this trend will be investigated in detail, notably the Corning-Bath and Van Etten-Odessa lineaments (fig. 7, main text).

The 334^o-357^o trend (P2, fig. C2 and Table C1) shows several zones of aligned lineaments (fig. C4). Of particular interest is the meridional swath centered at 77^{o}W. Whereas the 307^o-330^o trend showed a deficiency of lineaments within this region, here, numerous north-northwest trending lineaments occur.

Several other lineament zones occur in the 334^o-357^o trend. These occur as long individual lineaments as well as aligned concentrations of lineaments. The following major lineaments of this trend will be discussed further in the main text: Van Etten-Towanda lineament, and the Painted Post-Blossburg, Seneca Lake - Elmira and Endicott-Syracuse lineament zones (fig. 7 - main text).

The 11^o-66^o trend was originally combined because there were few wide significant troughs within this azimuth range on which to confidently subdivide the range. Examination of this trend (P3, fig. C2 and Table C1) suggests that there are several individual trends within the trend (fig. C5). This example demonstrates the heuristic nature of the analysis. A steadfast acceptance of a given probability level of significance may lead to useful results in one portion of the frequency-azimuth histogram and ambiguities in another portion. The grouped 11^o-66^o range was then subdivided on the basis of the narrow significant troughs, producing three subsets within the range of 11^o-21^o, 22^o-48^o, and 49^o-66^o (peaks P3a, P3b, and P3c respectively, fig. C2 and Table C1).

The 11^{o}-21^{o} trend shows several gaps in lineament density (fig. C6). Whether this trend is of geologic significance is difficult to ascertain because the total sample size is relatively small.

The 22^{o}-48^{o} peak (fig. C7) shows two bands of low lineament density; one is latitudinal at 42^{o}N between 77 1/2^{o}W to 76^{o}W, the other is submeridional, centered at 77^{o}W and striking approximately N30^{o}E. The latitudinal density minimum appears to coincide with the surface outcrop pattern of the Devonian Gardeau Formation, which consists predominantly of shales and which suggests a lithologic control. Other formations of the region contain greater proportions of siltstones. The northeast trending density minimum is enigmatic.

The 49^{o}-66^{o} peak shows two apparent areas of low lineament densities (fig. C8). One trends approximately northeast, beginning near the bottom of the map at 77^{o}W longitude. The other, trends about north-northeast and is centered about 77.5^{o}W longitude. Interestingly, the latter of these two zones coincides with a concentration of lineaments in the 11^{o}-48^{o} range (cf. figs. C5 and C8).

The Cortland-Ithaca lineament and the adjacent and subparallel Watkins Glen-Taughannock lineament zone, which form prominent patterns on the mosaic (fig. 2a, main text) and are outlined in figure 7 (main text), will be discussed in detail elsewhere in this study. Components of these two lineaments are present in two of the azimuth range maps (figs. C7-C8).

The 72^{o} - 79^{o} trend (P4, Table C1 and fig. C9) defines a relatively small but significant group of lineaments, which closely parallels the trend of the Alleghanian fold axes. This trend is virtually non-existent in the north half of the map. This may in part be due to intense glacial erosion (Staheli, 1971) in this area, effectively subduing the northeast oriented topography, but may also be due to the lower amplitude of the Alleghanian folds at the surface in the north. The Van Etten-Candor lineament (fig. 7, main text) has been chosen as representative of this direction and will be discussed later.

Significant peaks in the frequency-azimuth distribution nearly form a continuum from 307^{o} thru north to 79^{o}; the remainder of the distribution between 80^{o} - 90^{o} and 270^{o}-306^{o} (fig. C10) forms a significant trough (Table C1 and fig. C2). Because this includes the direction which is nearly parallel to the Landsat scan lines, the operators may have missed some lineaments. It also is possible that they were reluctant to map apparent linear features trending in these directions for fear of mapping data artifacts, the scan lines. A bias introduced by the angle of sun illumination can be ruled out, as these azimuths diverge from 15^{o} to 70^{o} from the illumination direction, suggesting that lineaments trending in these directions should be readily discernible. The longest lineament in this frequency azimuth trough set may be an extension of the Corning-Bath lineament (fig. 7, main text) and will be discussed under that heading.

References

Rodgers, J., 1970, The Tectonics of the Appalachians; Wiley-Interscience, New York, 271 p.

Sawatzky, D. L., and Raines, G. L., in press, Geologic uses of linear-feature maps derived from small-scale maps, in Proceedings of the 3rd International Conference on Basement Tectonics, (O'Leary, D.W. and Earle, J. L., eds.), Basement Tectonics Committee, Denver, Colorado.

Staheli, A. C., 1971, Topographic criteria for recognition of a threshold of erosion by the Laurentides ice sheet; unpublished PhD thesis, University of North Carolina, 82 p.

Wise, D. U., 1969, Regional and sub-continental sized fracture systems detectable by topographic shadow techniques, in Conference on Research in Tectonics (Kink bands and Brittle Deformation) (Baer, A. J., and Norris, D. K., eds.); Canada Geological Survey Paper 68-52, p. 175-199.

FIGURE CAPTIONS

Figure	
C1	Plot of all lineaments shown in figure 6 of the main text. Key to symbols: B - Bath, NY; Bl - Blossburg, PA; Cr - Corning, NY; Ct - Cortland, NY; El - Elmira, NY; En - Endicott, NY; It - Ithaca, NY; T- Towanda, PA; WG - Watkins Glen, NY.
C2	Plot of length-weighted frequency vs. azimuth for the 506 lineament mapped in the study. Single underscores - significant troughs; double underscores - significant peaks.
C3	Plot of lineaments falling within peak P1. North is at top of plot; distance between tic marks along axes is approximately 9.2 Km (5.75 miles)
C4	Plot of lineaments falling within peak P2. Scale same as fig. C3.
C5	Plot of lineaments falling within peak P3. Scale same as fig. C3.
C6	Plot of lineaments falling within peak P3a. Scale same as fig. C3.
C7	Plot of lineaments falling within peak P3b. Scale same as fig. C3.
C8	Plot of lineaments falling within peak P3c. Scale same as fig. C3.
C9	Plot of lineaments falling within peak P4. Scale same as fig. C3.
C10	Plot of lineaments falling within trough T1. Heavy dashed line indicates the average scan line direction of the Landsat multispectral scanner (MSS). Scale same as fig. C3.

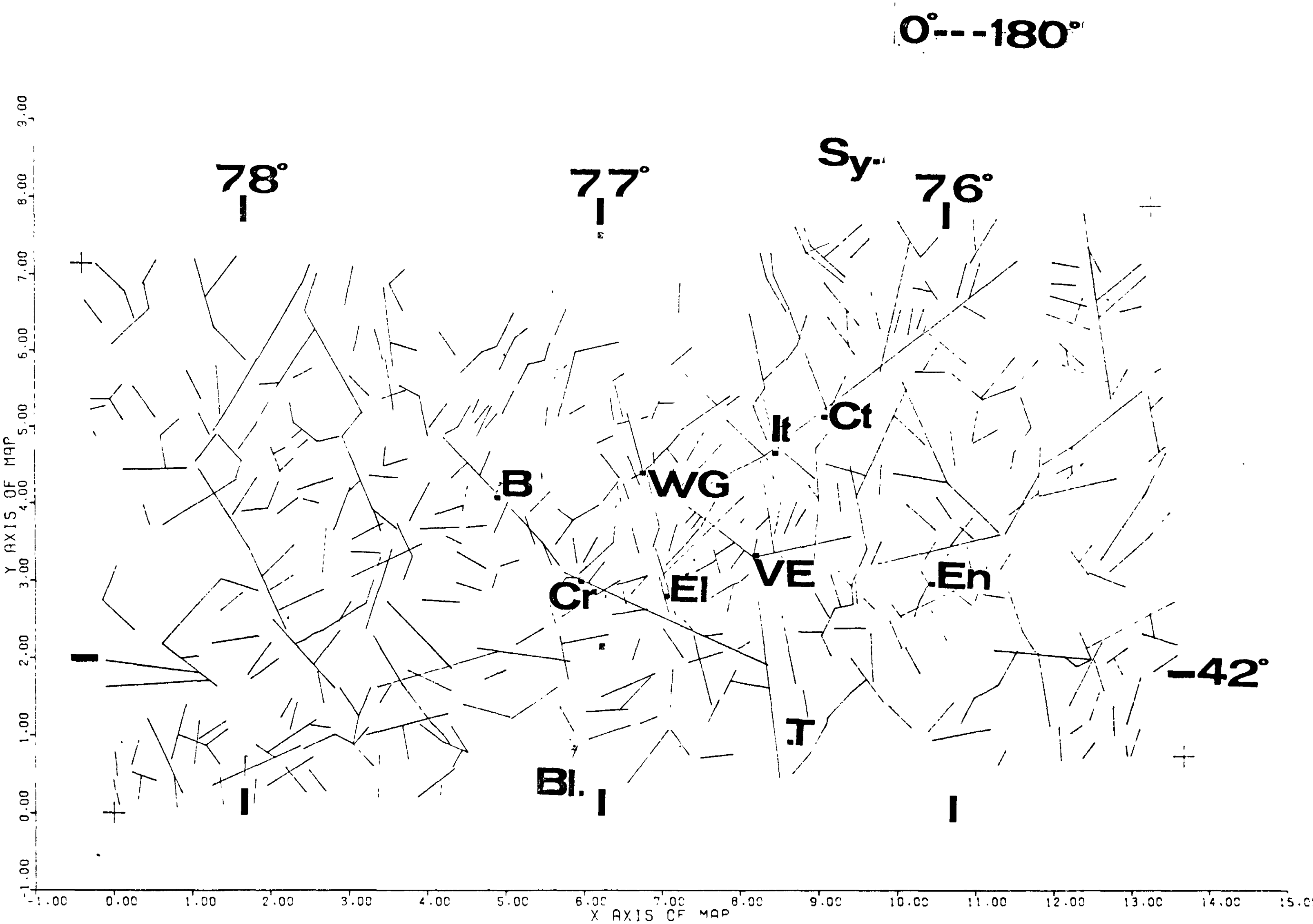
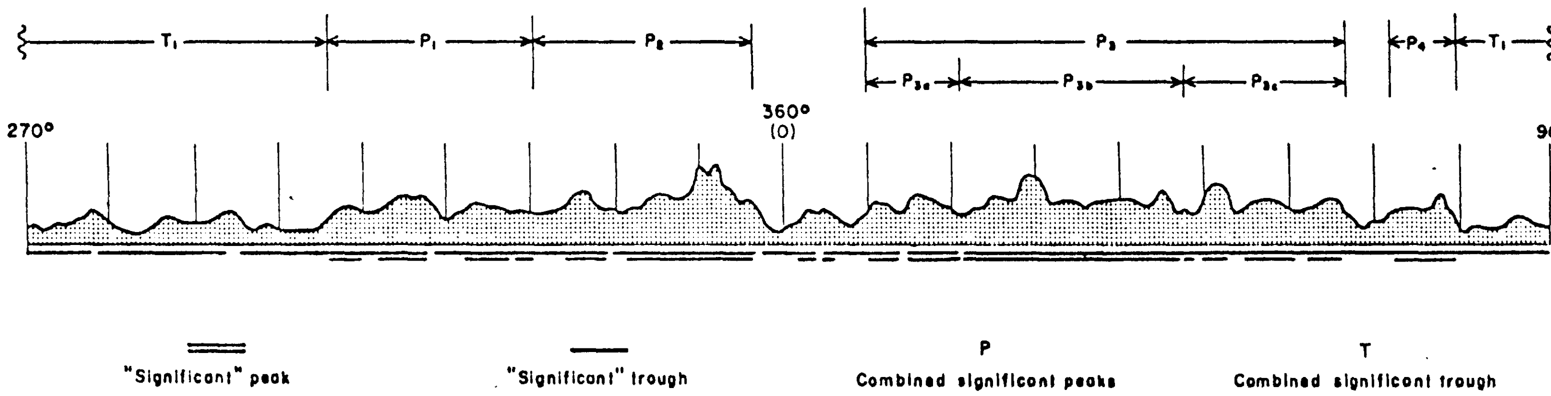

0°---180°
78°
77°
Sy
76°
B
WG
It
Ct
Cr
El
VE
En
-42°
T
Bl.
Y AXIS OF MAP
X AXIS OF MAP

FIGURE C1



T₁
P₁
P₂
P₃
P₃a
P₃b
P₃c
P₄
T₁
270°
360°
(0)
90°
"Significant" peak
"Significant" trough
P
Combined significant peaks
T
Combined significant trough

FIGURE C2

307°--330°

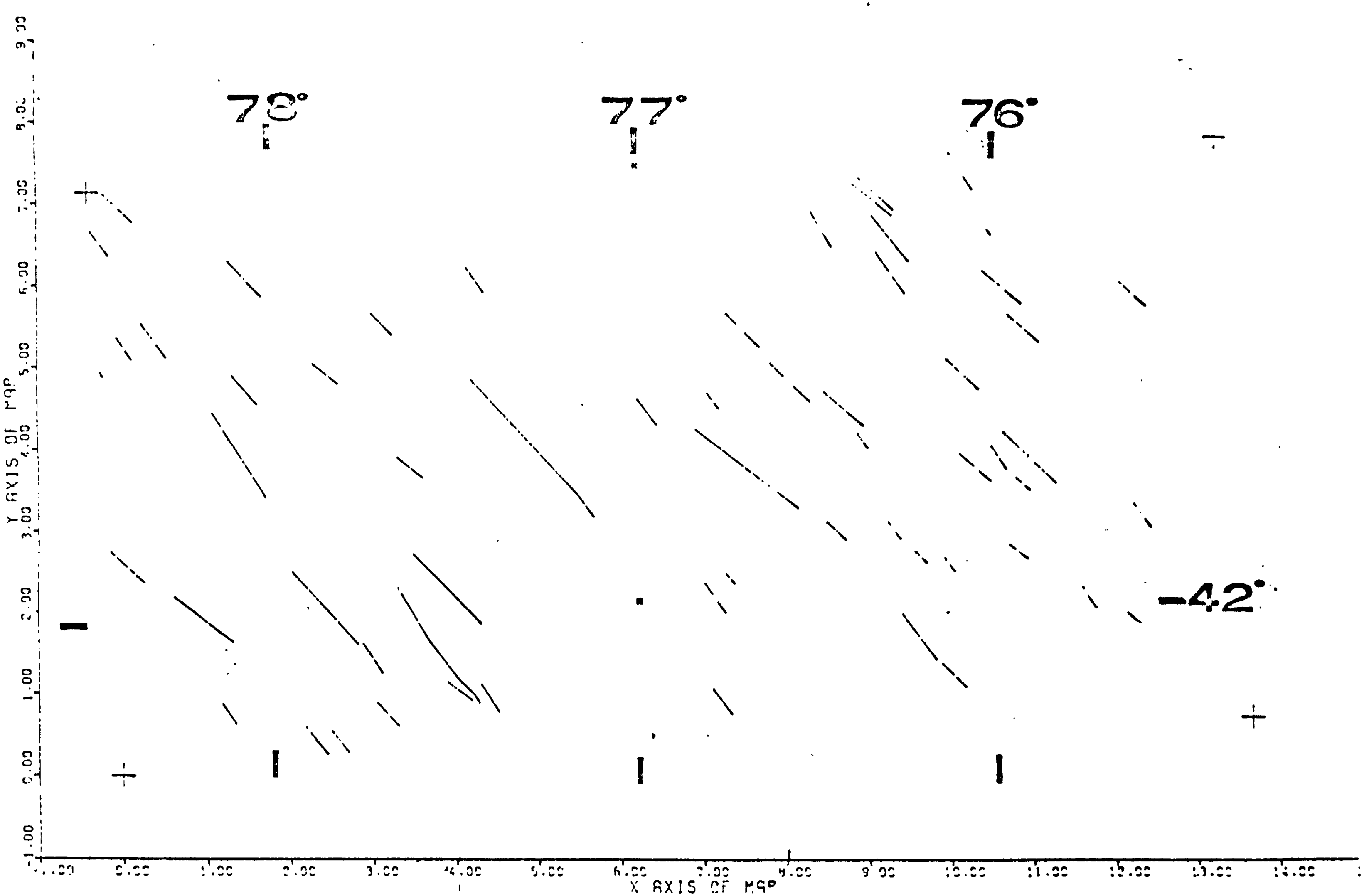


FIGURE C3 n=69

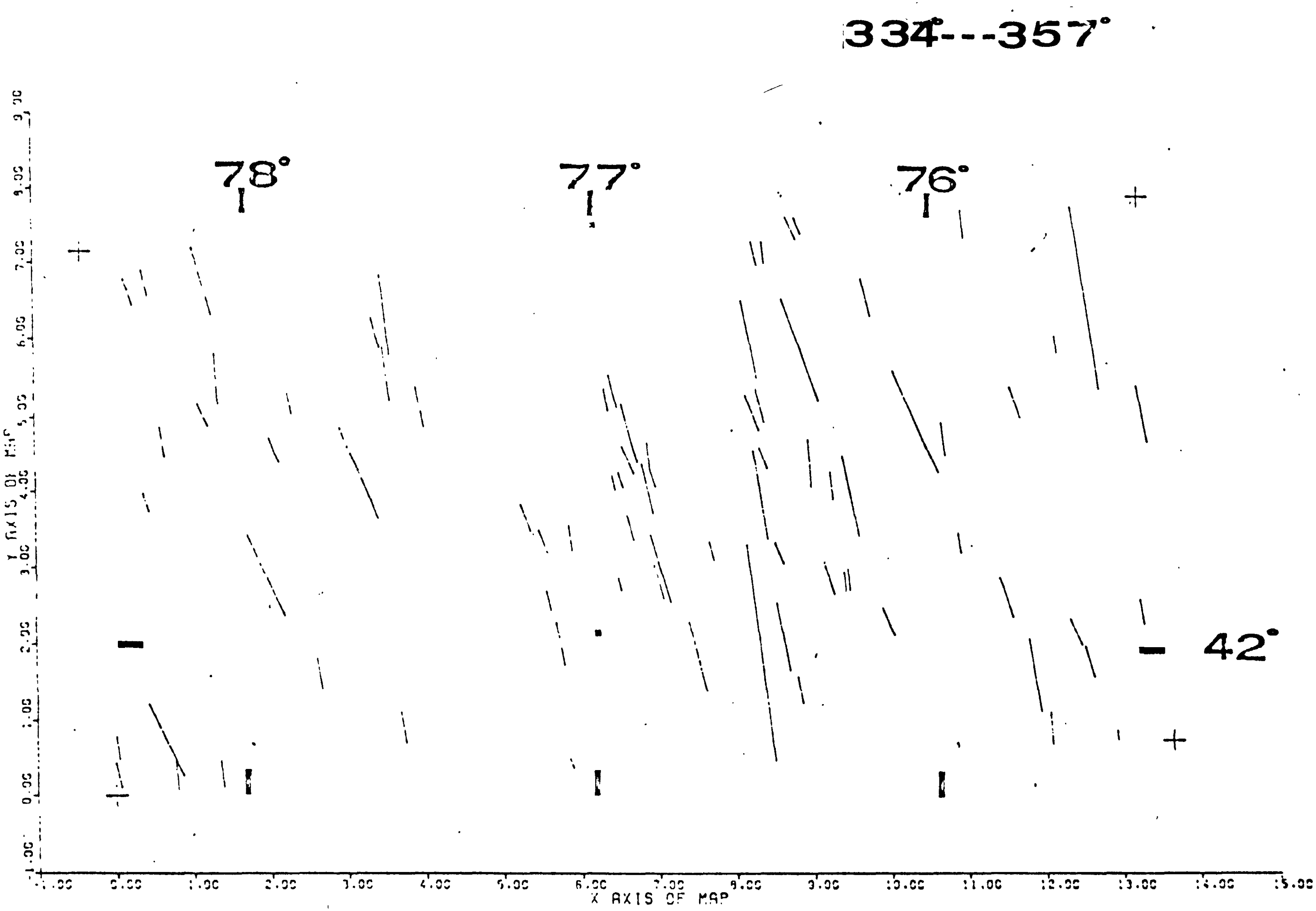


FIGURE C4 n=85

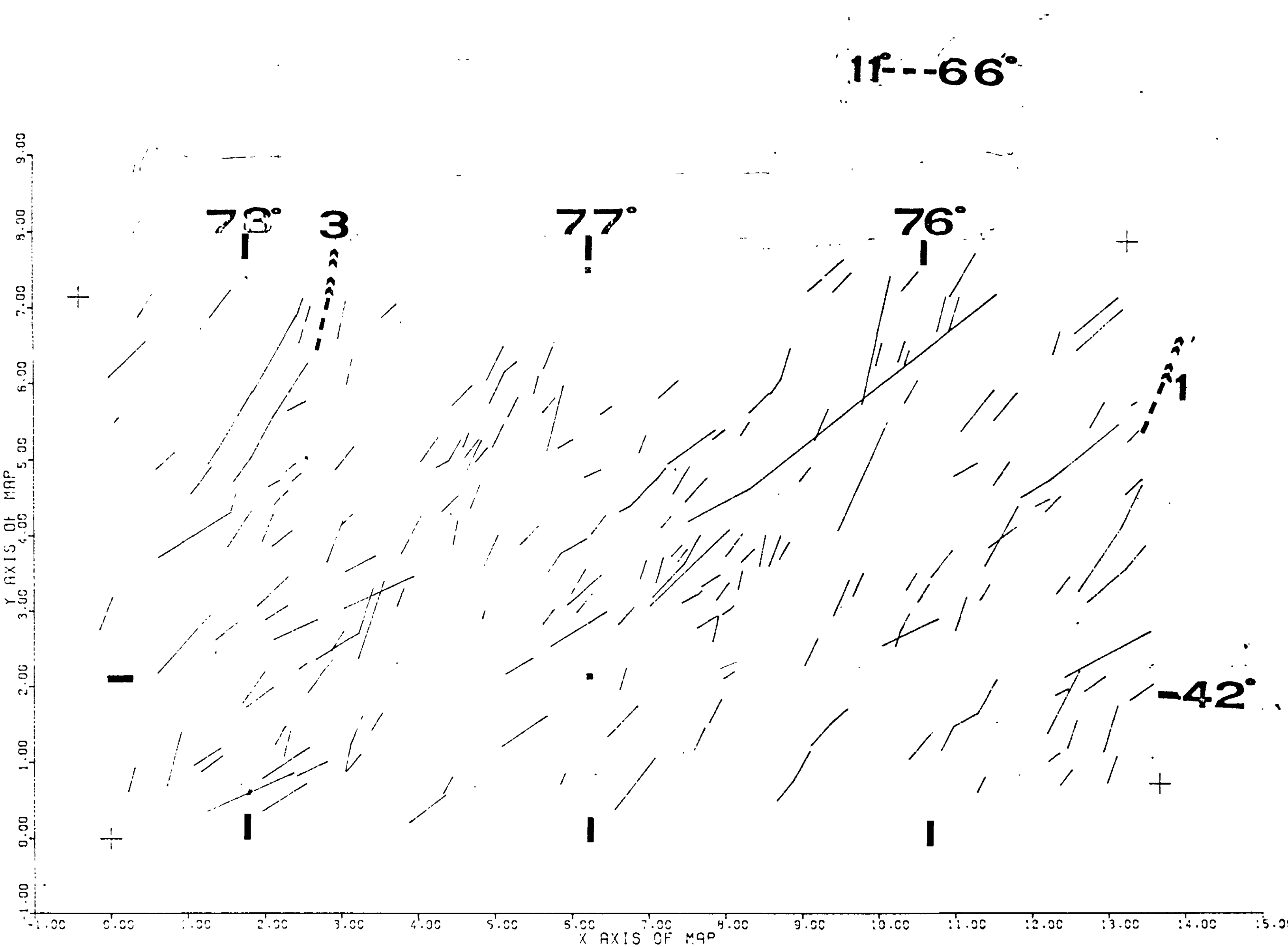


FIGURE C5 n= 213

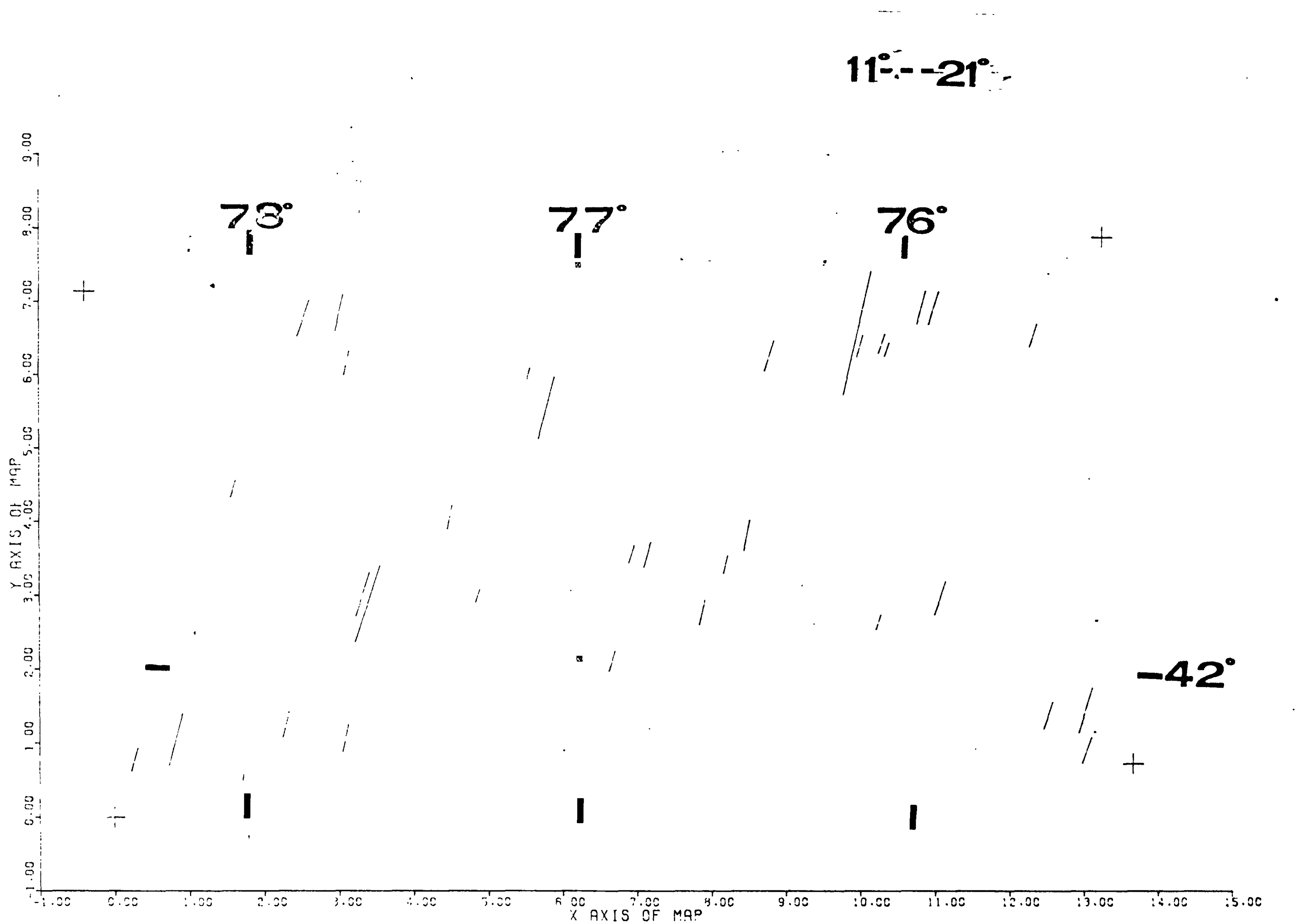


FIGURE C6 n=34

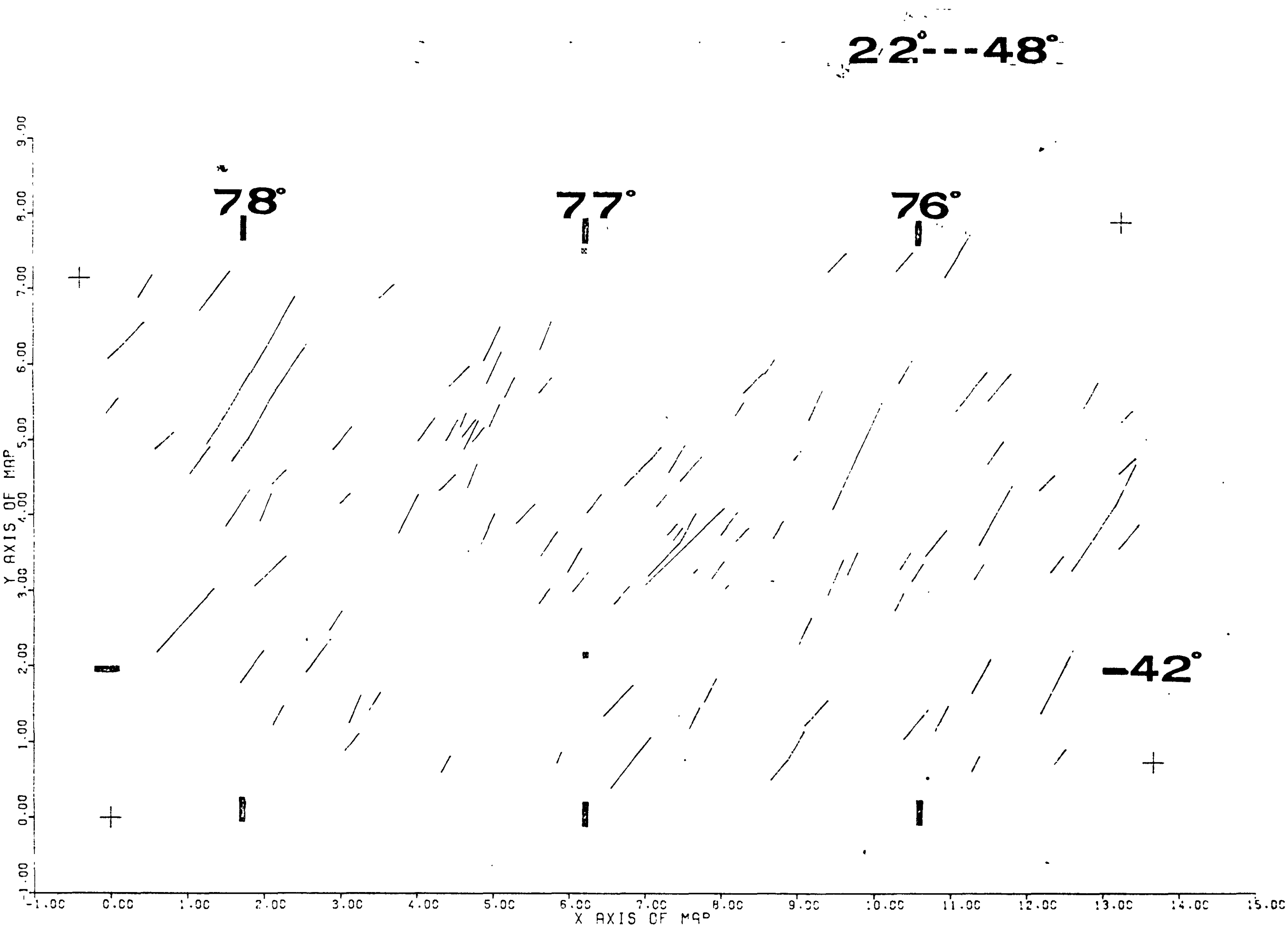


FIGURE C7 n=117

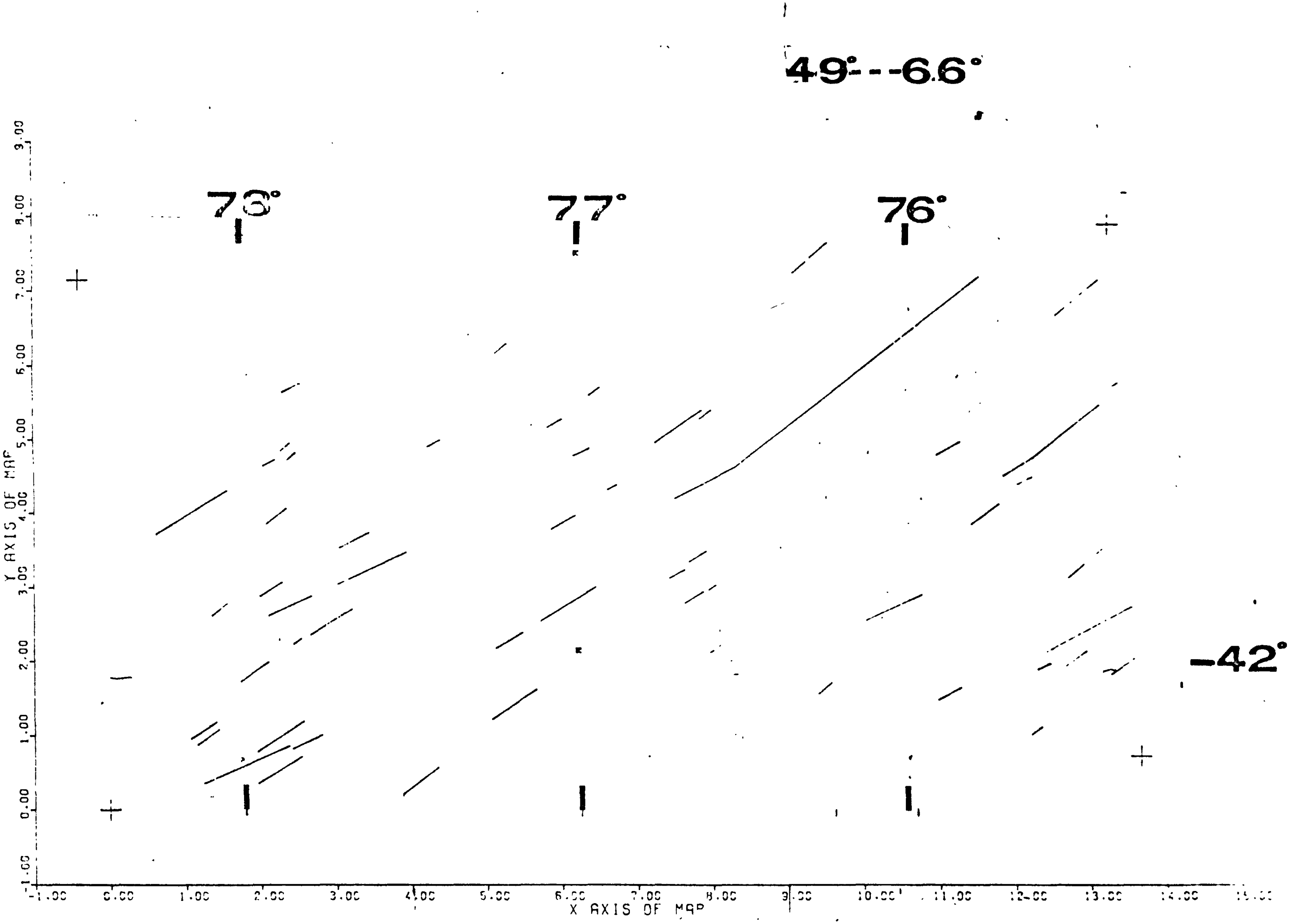


FIGURE C8 n=62

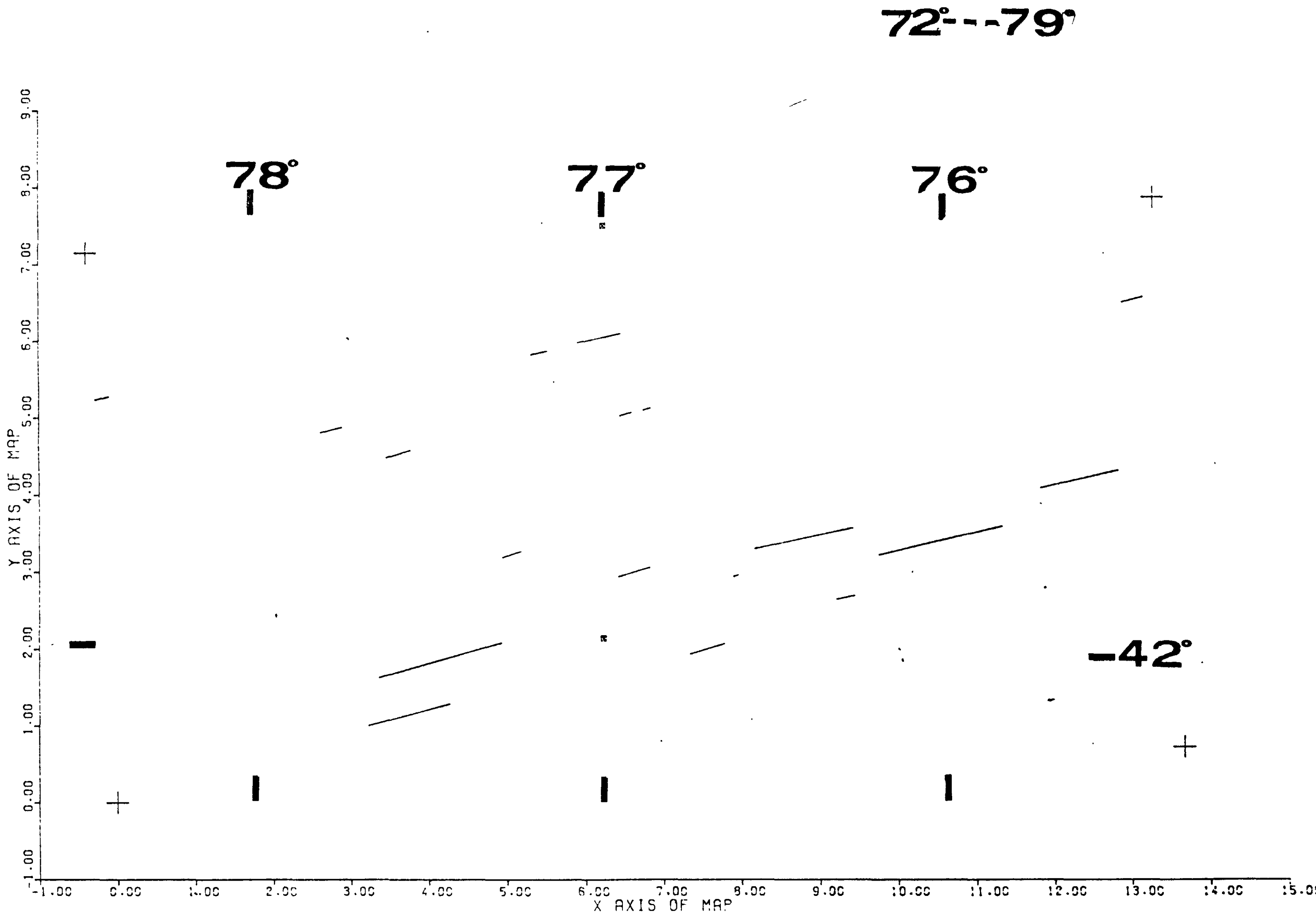


FIGURE C9 n=17

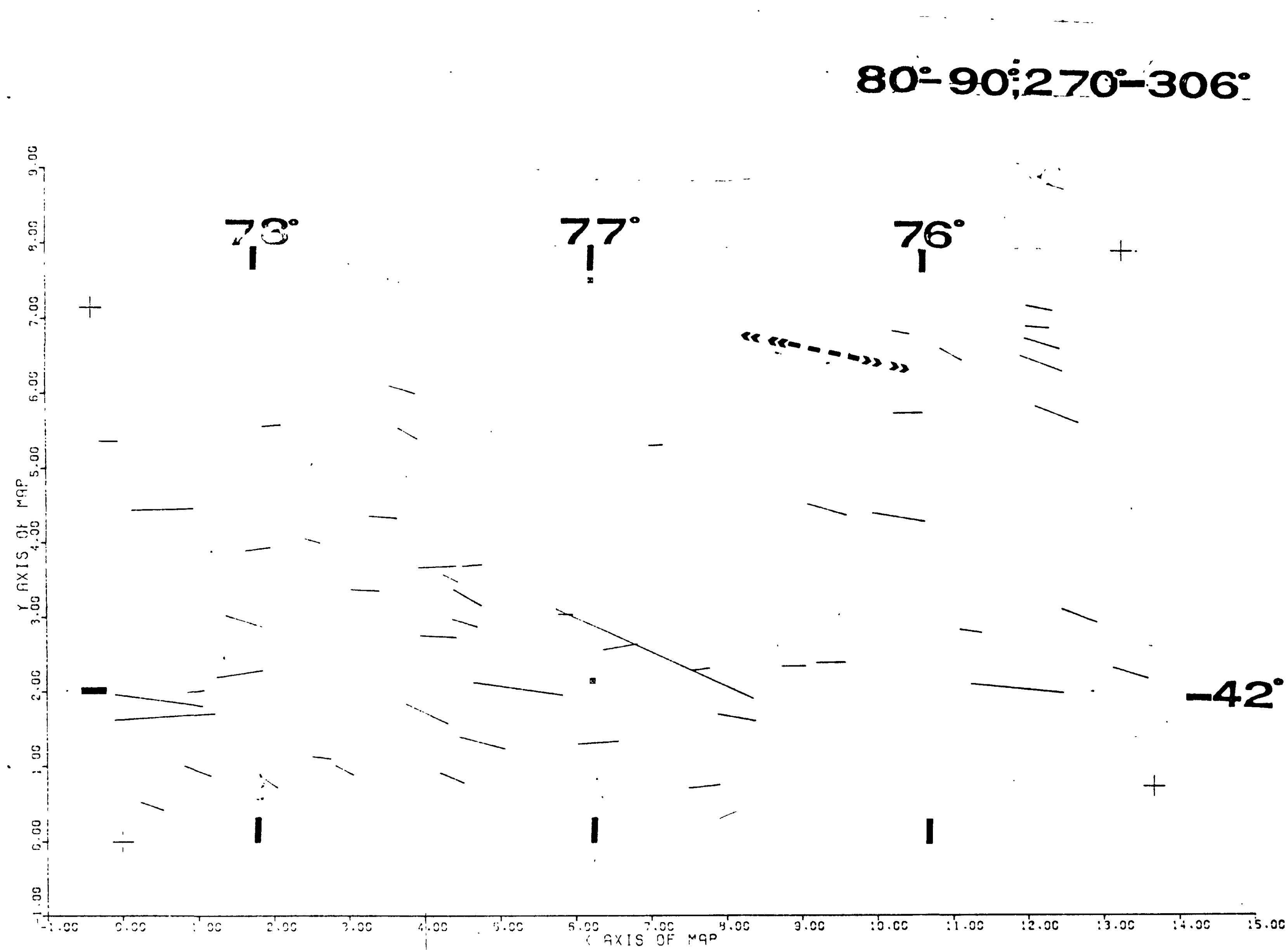


FIGURE C10 n=57

APPENDIX D
PENCIL SILTSTONES: A SURFACE INDICATOR OF FAULTING IN NORTHERN PENNSYLVANIA AND SOUTH-CENTRAL NEW YORK

INTRODUCTION

Pencil siltstones are bundles of acicular siltstones which represent closely spaced fractures that are normal to bedding (fig. D-1, a,b). Typically the individual pencils are 1/4 to 1/2 centimeter wide, five to fifteen centimeters long and 1/4 to one centimeter thick (or the depth to the subjacent bed). Outcrops of pencil siltstones in stream beds have been observed to be as wide as 10 meters and as long as 75 meters. The actual extent of a zone of pencil siltstones has never been observed due to the small size of most outcrops, and in fact even the largest observed outcrops of pencil siltstones are buried by alluvium at each end.

Although pencil siltstones have been commonly reported in the shales of the Ordovician Martinsburg formation in southeastern New York and southeastern Pennsylvania (T.H. Offield, U.S.G.S.; David MacLachlan, Pennsylvania Geological Survey, oral communication) the occurrence of pencil siltstones on the Allegheny Plateau is quite rare, and the phenomenon is seen on fewer than one-half percent of the outcrops.

Pencil cleavage in siltstones, shales, and slates has been observed by Cloos (1946), Crook (1964), and most recently by Engelder and Geiser (1979). These last authors felt that the presence of acicularly cleaved siltstones and shales were "an indicator of the pervasiveness of lateral shortening within the sedimentary sequence of the Appalachian Plateau" (Engelder and Geiser, 1979). They further pointed out that the long axis of the individual pencils conformed, in general, to the trend of folds in the "Appalachian Plateau."

We differ in our interpretation of the meaning of pencil siltstones, because many of the pencil siltstones we have observed in New York and Pennsylvania have long axes which are at a considerable angle to, and are sometimes normal to, the folds of the Allegheny Plateau. In addition, most pencil siltstones can be shown to have a definite spatial relationship to known or strongly suspected faults.

Location of pencil siltstones along observed faults: (figs. D-2, D-3, D-4)
1) West Danby, New York fault zone

The West Danby fault zone is a surface manifestation of faults whose subsurface expression have been recognized in seismic sections and well data. At the surface, the probable location of the faults is recognized by anomalous dips (as much as 15°) in an area where the normal maximum dips are one to three degrees. The faults strike nearly E-W in a zone that varies from 2-1/2 to 4 kilometers wide and extend from southeast of the town of Catherine (C, fig. D-4) eastward to the longitude of the town of West Danby (WD, fig. D-4) - a distance of 24 kilometers. The fault zone appears to be composed of at least two thrust faults translated to the north and one antithetic thrust translated to the south.

One-half kilometer east of Catherine (C, fig. D-4) at a ditch on the south side of the road there is an exposure of pencil siltstones whose strike is N85W. The pencil siltstone locality is at the westernmost end of the antithetic thrust.

2) The Roaring Branch-Monroeton, Pennsylvania fault zone

Pohn-and Purdy (1979) discovered an heretofore unknown antithetic thrust-fault zone along the northern edge of the Barclay syncline in Pennsylvania. The fault zone varies in width from one-half to one kilometer and extends from five kilometers WSW of Roaring Branch (RB, fig. D-4) to just south of Monroeton (M, fig. D-4) - a distance of 53 kilometers. To date, two occurrences of pencil siltstones have been found along this fault zone. The first occurrence is one kilometer north of Franklin Center (FC, fig. D-4). The pencil siltstones are in a stream valley exposure two meters from an obvious low-angle thrust fault. The sense of movement cannot be determined in the exposure, but the strike of the pencils is N19W. The second occurrence was recently discovered by George W. Colton of the U.S. Geological Survey (pers. comm., 1979). This occurrence is in roadcut 1.5 km east of Franklin Center (Powell, Pa. 7-1/2 minute quadrangle). In the upper siltstone beds the long axes of pencils strike both N53E and N33E and a lower shale bed in the outcrop has aciular cleavage whose long axis strikes N39E.

Williamsport Valley, Pennsylvania fault zones

3) Cogan Station Fault zone

In the northernmost fault zone of a system of six intensely folded and faulted zones in the Williamsport Valley (Pohn and Purdy, 1979), a faulted "step fold" 1 kilometer east of Cogan Station (CS, fig. D-4) exhibits pencil siltstones along the fault. At this locality the pencils strike N5W.

4) South Loyalsockville fault zone

1.2 kilometer ESE of the town of South Loyalsockville (S, fig. D-4) in an area of "staircase" folds (Pohn and Purdy, 1979a), pencil siltstones strike N82E.

5) The Farragut Fault Zone

2.6 kilometers due east of the town of Farragut (E, fig. D-2) in a roadcut on Highway 864 a single "step" fold accompanied by numerous thrust faults which are offset up the "step"; there pencil siltstones strike N55^{o}E.

6) The Grampian Hills Quarry Fault

In a quarry at the west edge of Grampian Hills adjacent to the town of Williamsport, a thrust fault of unknown, but large (greater than 40 meters) displacement has been discovered. The fault is a synthetic thrust (upper plate translated northward). The long axes of the pencil siltstones associated with the fault strike N20E.

Pencil Siltstones along the projection of known faults:

7) The Bridge Street, Towanda, Pennsylvania fault (G-G, fig. D-2)

Pencil siltstones associated with the antithetic thrust fault at Bridge Street, Towanda, Pa. (T, fig. D-4), differ from the previous localities in that pencil siltstones are not found at the outcrops which show the fault but are found along the southwestward projection of the fault. The strike of the fault at Bridge Street is N80E. Southwestward along this strike, is an outcrop of pencil siltstones 0.5 kilometer NNW of Granville Center (GC, Fig. D-4) a distance of 22 kilometers from the Bridge Street exposure. The direction of acicularity of this locality is N10^{o}E and probably marks a small tear fault along the front of the thrust. Continuing along the S80W strike, pencil siltstones are present 29 kilometers from the Bridge Street outcrop. This second outcrop is 3.2 kilometers NE of the town of East Canton and there the pencils strike N64E. At distances of 34.5, 41, and 49 kilometers from Towanda pencil siltstones occur whose strikes are N69E, N64W, and N69E respectively. This line of outcrops is most probably along the Bridge Street-Towanda fault and all the pencil siltstone occurrences are generally aligned along a broad ogive which is subparallel to the north facing edge of the Barclay Syncline.

Pencil siltstones along suspected faults:

Two groups of pencil siltstones lie along zones of possible faulting as evidenced by either Landsat lineaments or changes in the orientation of major structures.

The Van Etten-Towanda Lineament (H-H, Fig. D-2)

One of the straightest, longest lineaments seen on the Landsat III RBV (Return-Beam Vidicon) images of southern New York and northern Pennsylvania is the Van Etten-Towanda lineament (see H, fig. D-2, D-3). It can be traced for a distance of 46 kilometers in a north-south direction, and disappears only where the Susquehenna River makes an abrupt turn to the southeast just south of Towanda. To date, six occurrences of pencil siltstones have been found along the west side of the lineament. The strikes of all of the pencil siltstones are within ten degrees of the strike of the lineament. Structure contour maps fig. 21, main text, this study as well as geophysical data (Appendices E & F, this study) indicate the presence of a probable fault in at least the New York portion of this lineament.

The Gillett-Blossburg Line (J-J, fig. D-2 and J, fig. D-3)

The Gillett-Blossburg line includes three outcrops of pencil siltstones along a line whose strike is N51E. The southward extension of this line intersects the northern edge of the Blossburg Syncline at a location where the strike of the synline changes abruptly from a strike of N77E to N60E. The strike of the line connecting the three outcrops is parallel to and aligned with the Rome trough (Harris, 1978).

Discussion

Pencil siltstones are typically found in the vicinity of faults, but their exact spatial relationship to the fault is, at present, unclear, and the mechanics which produce the phenomenon is unknown. Most pencil siltstones are epxosed near thrust faults appear to have their long axes parallel or subparallel to the front of the thrust. This would imply that the pencils may be related to splay faults from the master decollement. Other pencil siltstones, particularly those along suspected tear faults, have their long axes parallel to the strike of the tear. The need for further investigations into the rock mechanics which produces pencil siltstones is clear. The uncertain mode of their formation does not invalidate the use of pencil siltstones as a viable tool for the location of suspected faults.

References

Cloos, E., 1946, Lineation; Geological Society of America Memoir 18, 122p.

Crook, K. W., 1964, Cleavage in weakly deformed mudstones, American Journal of Science, v. 262, p. 523-531.

Engelder, T. and Geiser, P., 1979, The relationship between pencil cleavage and lateral shortening in the Devonian section of the Appalachian Plateau, New York, Geology, vol. 7, p. 460-464.

Harris, L. D., 1978, The eastern interior aulacogen and its relation to Devonian shale-gas production; Proceedings 2nd Eastern Gas Shales symposium, Morgantown Energy Technology Center, SP - 78/6, p. 55-72.

Pohn, H. A. and Purdy, T. L., 1979, Decollement in the southern Allegheny plateau of Pennsylvania, U. S. Geological Survey, Open-File Report 79-1321.

Pohn, H. A. and Purdy, T. L., 1979a, Thrust fault zones in the Allegheny plateau of north-central Pennsylvania, U. S. Geological Survey Open-File Report 79-1604.

Rodgers, J., 1970, The tectonics of the Appalachians, Wiley-Interscience pl. 1.

FIGURE CAPTIONS

D 1 a - A fresh outcrop of pencil siltstones. b - Weathered pencil silstones in a stream valley. Note camera lens cap for scale.

D 2 Map of the location and orientation of pencil siltstones in south-central New York and north-central Pennsylvania. A - West Danby occurrence, B - Roaring Branch - Monroeton occurrences, C - Cogan station occurrence, D - South Loyalsockville occurrence, E - Farragut occurrence, F - Grampian Hills occurrence, G - Bridge Street-Towanda occurrences, H - Van Etten-Towanda occurrence, J - Gillett-Blossburg Line, K - Rodgers' Lineament.

D 3 Map of surface structures in south-central New York and north-central Pennsylvania. A - West Danby fault zone, B - Roaring Branch - Monroeton fault zone, C - Cogan Station fault zone, D - South Loyalsockville fault zone, E - Farragut fault zone, F - Grampian Hills fault zone, G - Bridge Street - Towanda fault zone, H - Van Etten-Towanda Line, J - Gillett-Blossburg Line, K - Rodgers Lineament.

D 4 Location map of place names used in the text. C - Cathrine, WD - West Danby, RB - Roaring Branch, M - Monroeton, FC - Franklin Center, CS - Cogan Station, S - South Loyalsockville, F - Farragut, G - Crampian Hills, T - Towanda, GC - Granville Center, VE - Van Etten, GL - Gillett, B - Blossburg.

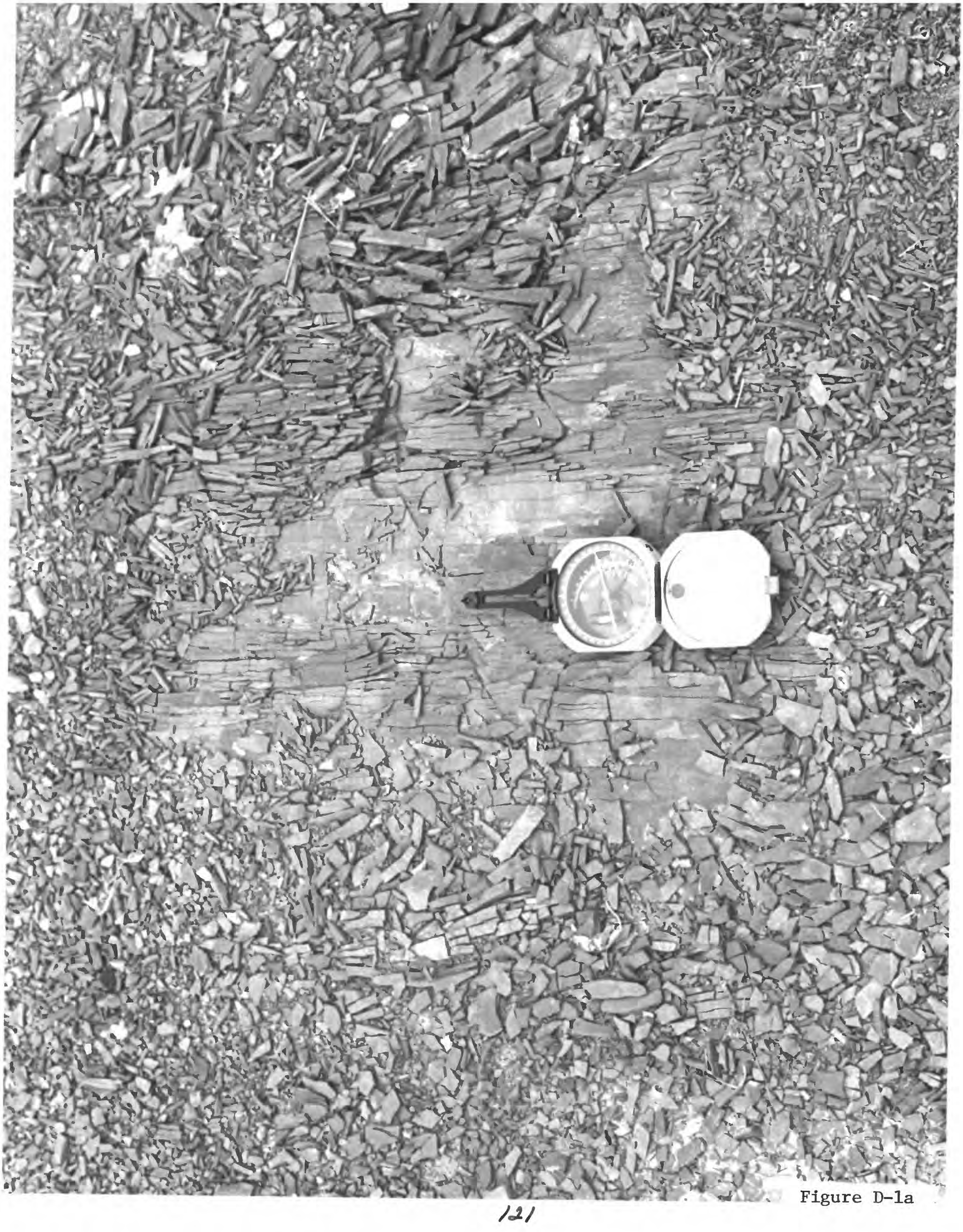


Figure D-1a

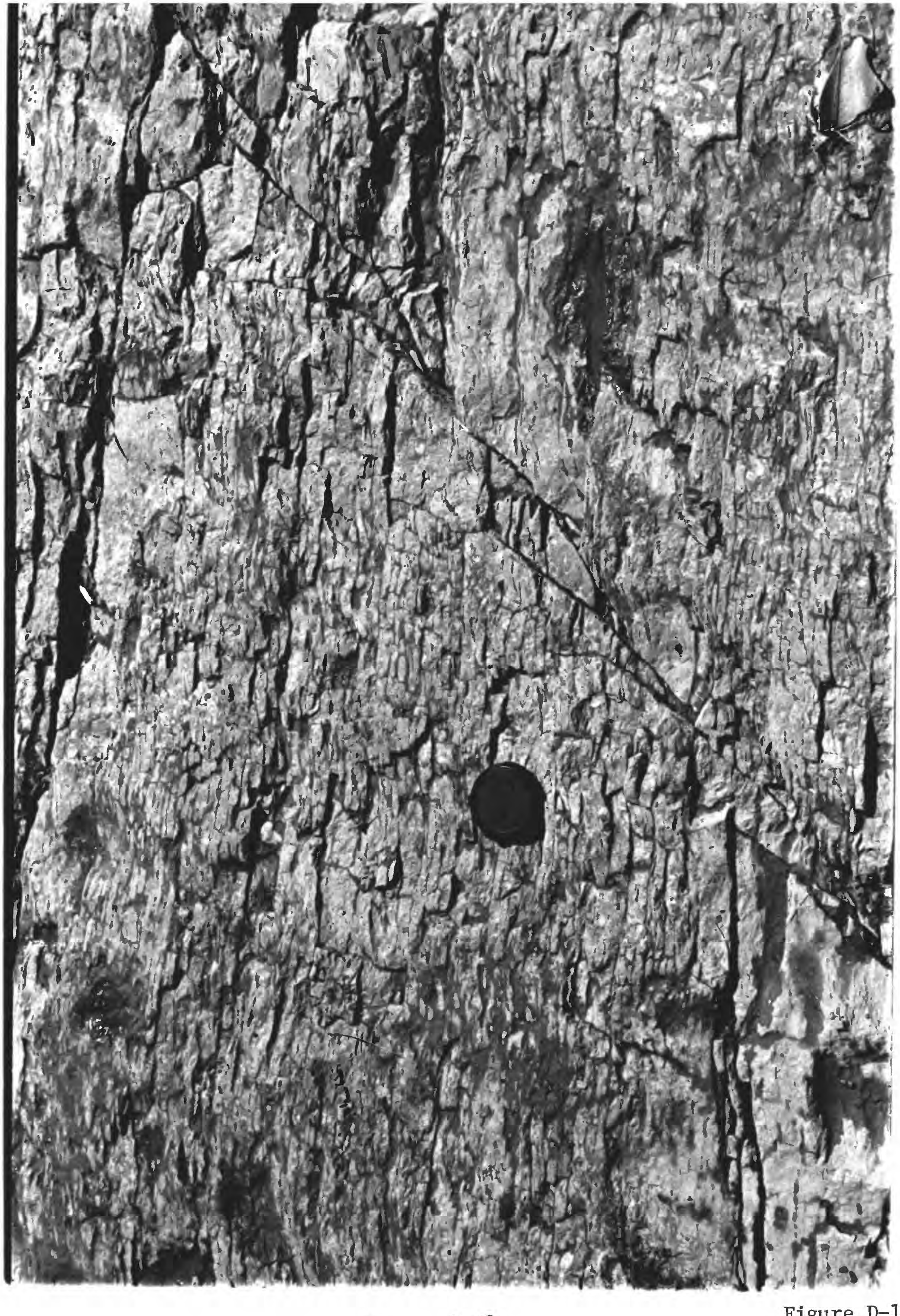
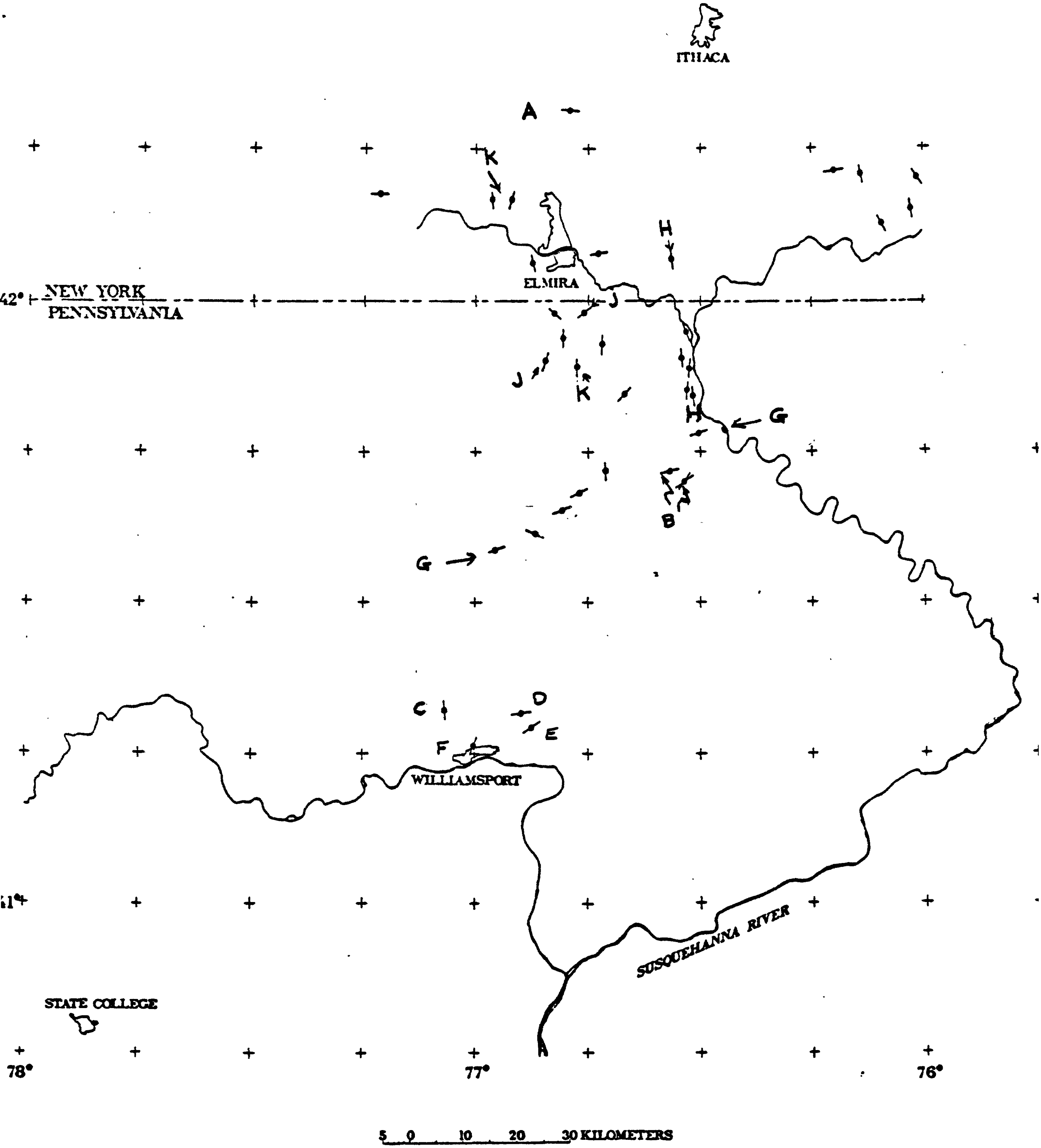
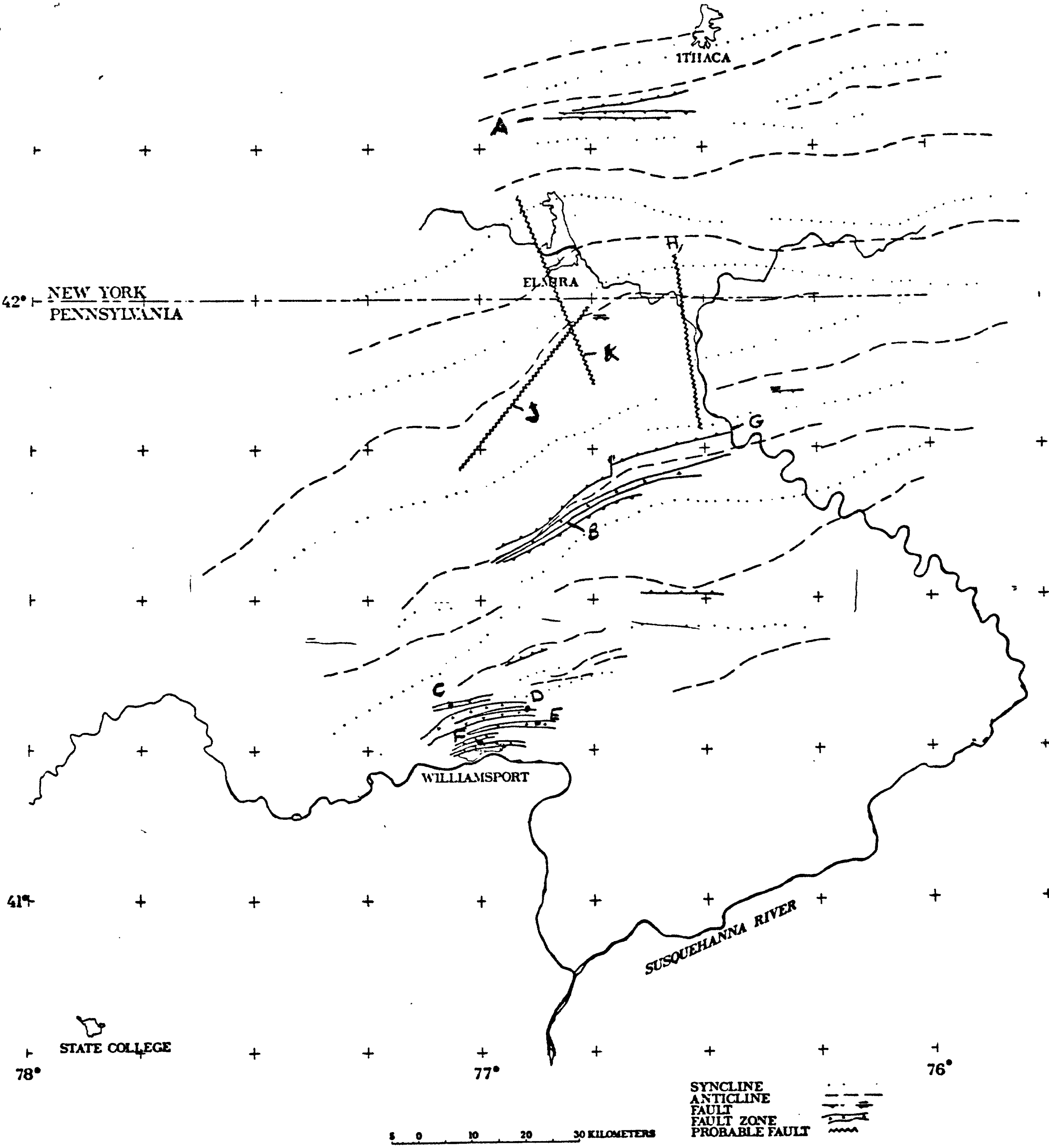


Figure D-1b



PENCIL SILTSTONES

Figure D-2



SURFACE STRUCTURES

Figure D-3

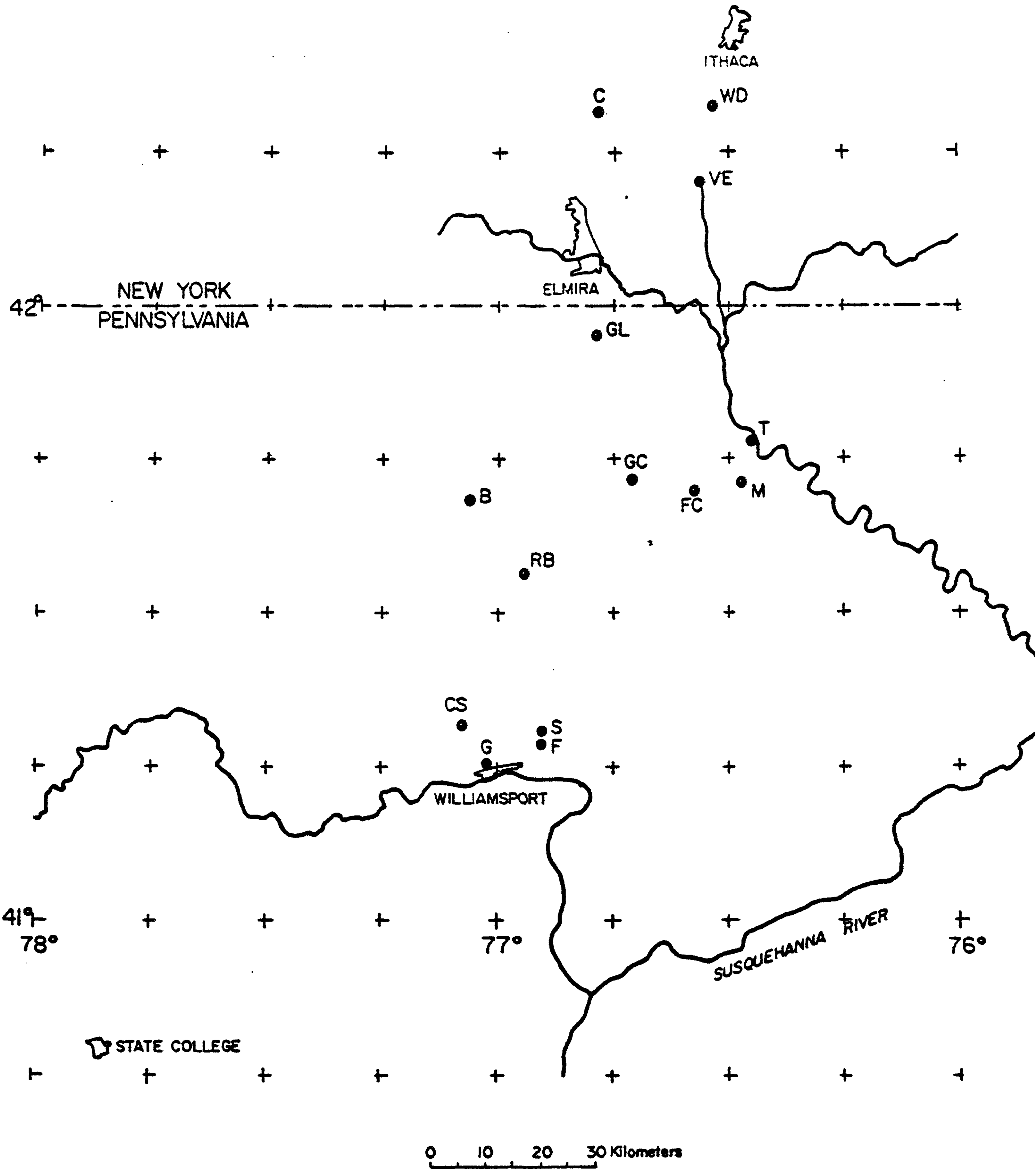

ITHACA
C
WD
VE
ELMIRA
42°
NEW YORK
PENNSYLVANIA
GL
T
GC
B
FC
M
RB
CS
S
G
F
WILLIAMSPORT
41°
78°
77°
76°
SUSQUEHANNA RIVER
STATE COLLEGE
0 10 20 30 Kilometers

Figure D-4

APPENDIX E: ANALYSIS OF AEROMAGNETIC AND GRAVITY DATA

The aeromagnetic data for westernmost New York State (USGS, 1975) and for central New York State (USGS, 1979) have been analyzed using both qualitative and quantitative techniques in order to determine the extent to which Landsat lineaments and known subsurface structures are controlled by the crystalline basement.

WESTERNMOST NEW YORK

Westernmost New York was the area chosen for the initial analysis. The data for the aeromagnetic map (figure E-1) were gathered at an elevation of 914 m (3000 ft) along east-west flight lines spaced 3.2 km (2 miles) apart.

The northern half of the aeromagnetic map is dominated by short-wavelength features such as the many intense positive circular anamalies indicative of mafic plutons within the crystalline basement. The circular amomalies become subdued in the southern half of the the map, where longer wavelengths dominate. This change in character reflects in part a gradual deepening of the crystalline basement surface from approximately 0.5 km below sea level near the nothern border of the map to approximately 2.5 km near the Pennsylvania border on the south.

One interesting feature of the aeromagnetic map is the arcuate north-south positive anomaly (expressed primarily in shades of yellow on the map) extending from near the upper right corner of the map to the right center. The western edge of this anomaly corresponds to the main trace of the Clarendon-Linden fault (Van Tyne, 1975).

In a portion of the aeromagnetic map near the Clarendon-Linden fault (figure E-2) the magnetic anomalies appear to have low order bilateral symmetry about a north-south axis. Corresponding peaks, troughs, and saddles on either side of the symmetry axis have been connected by line segments. Although the connecting line segments are not quite parallel, their midpoints define the symmetry axis remarkably well.

Bilateral symmetry in magnetic data over oceanic crust often provides evidence for rifting of the sea-floor-spreading variety (Vine and Wilson, 1965). Axially symmetric potential field anomalies over continental crust may also arise from extensional tectonics (Eaton and others, 1978), but the mechanism for emplacement of plutons is likely to be quite different from the mechanism for formation of new sea floor. Most likely, plutons would be emplaced along deep fractures parallel to the rift axis. Symmetrical magnetic anomalies would arise if the plutons were most easily emplaced at the intersections of these parallel fractures and a small number of fractures perpendicular to the rift. Later in this report other evidence will be presented suggesting that the Clarendon-Linden fault zone is associated with a failed Precambrain rift.

At high magnetic latitudes second vertical derivative maps of the magnetic field can be useful in outlining causitive magnetic bodies (Bhattacharyya, 1965). The zero contour of the second vertical derivative map will approximate the contact between magnetic and nonmagnetic material. A comparison of the second vertical derivative map (figure E-3) with the aeromagnetic map can yield a magnetic lithology map of the basement which outlines the mafic bodies responsible for the intense magnetic anomalies. Correlations between the second vertical derivative map and less intense magnetic anomalies may indicate either silicic intrusives or structural features such as domes and horsts. The magnetic lithology map (figure E-4) clearly shows a lack of mafic material in the southeast and southwest corners of the area. The intrusives tend to be elongated in a north-northeasterly direction, parallel to the Clarendon-Linden fault zone. In addition, there are a few intrusions that trend northwest.

Figure E-5 presents structure contours at the top of the Precambrian crystalline basement as determined from deep wells (Kreidler, 1959, 1963; Kreidler and others, 1972; Wallace and deWitt, 1975). The basement appears to dip uniformily to the south-southeast, although the distribution of basement wells is quite sparse at depths greater than 1 km below sea level. Also shown in the figure is the projected location of the Clarendon-Linden fault system. Van Tyne (1975) estimates that displacements on the basement due to this fault system are on the order of 30 meters.

In an attempt to improve the resolution of the basement topography and structure, a source-depth analysis was performed on the aeromagnetic data. The technique used (Phillips, 1979) employs autocorrelation analysis along the east-west flight lines. Source depths are estimated only where the calculated autocorrelation function matches the theoretical autocorrelation function of a thin dike anomaly. The resulting magnetic basement map (figure E-6) is based on all magnetic depth estimates, but only the 1 km and 2 km contours are shown. For the most part, the magnetic basement surface agrees with the available basement wells. In the northern part of the area magnetic basement is occassionally seen to be deeper than the crystaline basement, indicating that some of the magnetic anomalies here arise from intrabasement sources.

It is unlikely that the isolated patches of shallow magnetic basement seen in the southeastern part of the area are due to actual basement topography. More likely they are due to either noise in the data or to actual shallow magnetic sources such as the kimberlite dikes exposed to the east near Ithaca (Martens, 1924). Steep gradients seen in figure E-6 do not necessarily represent the crystalline basement topography. Instead they may indicate locations where the dominate magnetic sources change from one level, such as the crystalline basement surface, to another level, such as an intrabasement horizon. Despite these uncertainties, it is possible to select contours from figure E-6 that agree closely with the basement wells. The main 2 km contour is particularly well defined, as is a 1 km contour running along and south of 43° N latitude.

Another source of information on basement structure is provided by the locations of the magnetic basement depth estimates. The locations of the depth estimates falling within the range 0 to 3 km below sea level (figure E-7) might be expected to agree most closely with structures at the crystalline basement surface. Of particular interest are sets of depth estimates that align themselves in roughly north-south directions. These represent linear magnetic sources such as changes in dip of the basement surface, the upper edges of basement faults, or lithologic contacts. The longest such set lies along and to the west of 78° W longitude. A less well defined set lies about 10 km farther west.

Figure E-8 is a map of linear basement structures as interpreted from the data of figure E-7. The structures are dotted across individual flight lines where depth estimates were absent. The figure suggests there is a north to north-northeast trending graben along the Clarendon-Linden fault zone (A-A′). The graben broadens abruptly to the south as the western border swings to the southwest. The magnetic basement (figure E-6) appears to be depressed in the center of the graben. The main (central) fault of the Clarendon-Linden fault zone follows the western border of the graben as far as the bend to the southwest. The eastern fault of the Clarendon-Linden fault zone either follows or lies to the west of the eastern border of the graben. It is interesting to note that the block defined by the central fault and the eastern fault is presently a horst (Van Tyne, 1975). This suggests that the crystalline basement under the fault zone is nonmagnetic and may be composed of Precambrian sedimentary rocks which were deposited within the graben and metamorphosed in Precambrian time. The present-day easterly oriented compressive stress regime (Sbar and Sykes, 1973; Fletcher and Sykes, 1977) is consistent with formation of a horst through partial closure of the graben and uplift of the metasedimentary fill.

In addition to the borders of the graben, there is one other major northeast trending linear structure shown (B-B′ in figure E-8). If this is a fault, then the magnetic basement contours south of 43° N latitude suggest its sense of motion is down to the southeast. The length of this feature, its trend and apparent sense of motion all suggest that it is another fault related to the graben.

Several northwest trending linear features (labeled C) are seen in figure E-8. Two of these are near the center of the map, two are in the southeast corner and one is in the southwest corner. The magnetic basement contours suggest that vertical displacements may be associated with these features, but the sense of motion appears to reverse repeatedly along their length, thus they may be explained as basement shear zones. The trend of these features suggests that they may form a conjugate set of fractures with the north-northeast trending set.

Burke (1980) has defined a continental rift as a large scale structure, represented by an elongate depression, and produced by extensional rupture of the entire thickness of the lithosphere.

Active rifts are characterized by broad gravity lows and axial gravity highs, by seismicity, and by magmatism. The Clarendon-Linden fault zone has many characteristics of a failed rift. It is a slightly arcuate feature, over 100 km long as mapped from the aeromagnetic anomalies, and extending under Lake Onterio for an additional unknown distance. The magnetic basement is depressed along its length, and the borders of the depression appear to be faulted. A magnetic high runs along the axis of the fault zone, providing evidence for magmatism and intrusion. A broader axial gravity high is also present. Intense circular magnetic anomalies, indicative of mafic plutons, are found in a belt at least 40 km wide about the fault zone. This suggests a deep zone of weakness existed at the time of intrusion. The current seismicity indicates the persistence of this weakened zone.

CENTRAL NEW YORK

The aeromagnetic map for central New York is shown in figure E-9. As before, the data were gathered at an elevation of 914 m (3000 ft) along east-west flight lines spaced 3.2 kms (2 miles) apart. In our interpretation, circular positive magnetic anomalies on the map indicate individual mafic plutons, and longer wavelength positive anomalies define intrusive complexes that encompass the individual plutons. A band of magnetic intrusives (A-A′ in figure E-9) trends across the map in a west-northwesterly direction. Two linear intrusive complexes trending northeast (B-B′ in figure E-9) are seen to the north of this band. Some lengthening of the dominant anomaly wavelengths is evident toward the south. This reflects the southward dip of the crystalline basement (Rickard, 1973). The only crystalline rocks exposed in the area are a few kimberlite dikes seen near Ithaca (Martens, 1924). These dikes and additional kimberlite dikes exposed near Syracuse have been dated as Early Cretaceous (Zartman and others, 1967). The dikes do not appear to produce anomalies on the aeromagnetic map, but the source of the Ithaca dikes may be one of the plutons near Ithaca (It).

The second vertical derivative map for central New York (figure E-10) has been converted into a lithologic interpretation map (figure E-11) based on the aeromagnetic map. Here the shaded areas indicate locations of magnetic plutons. The wide stipple pattern defines a possible reversely-magnetized pluton.

Structure contours on top of the crystalline basement have been estimated from deep wells (figure E-12). Both the depth and the dip of the basement surface are seen to increase to the south, but the distribution of basement wells is sparse at depths greater than 1.5 km below sea level.

The magnetic basement surface has been interpreted from the aeromagnetic data (figure E-13). In order to emphasize sources near the crystalline basement surface, only the upper three kilometers of the magnetic basement surface have been contoured.

In the northern part of the area the magnetic basement tends to be slightly deeper than the crystalline basement, thus a reliable 1 km contour cannot be defined from the magnetic basement. With the exception of two northerly reentrants, the main 2 km contour of the magnetic basement agrees well with the 2 km contour of the crystalline basement. The 3 km contour of the crystalline basement, like the 1 km contour, cannot be defined from the magnetic basement, again because the magnetic sources appear to be deeper than the crystalline basement surface. The precautions mentioned earlier regarding the interpretation of steep gradients in the magnetic basement, and regarding the effects of shallow magnetic sources and noise clearly apply to the interpretation of figure E-13.

The locations of magnetic depth-estimates in the range 0 to 4 km below sea level (figure E-14) may define structures at the surface of the crystalline basement. A comparison of interpreted basement structures (figure E-15) with the magnetic basement contours (figure E-13) suggests that many of the longer northeast trending structures may be faults defining horsts and grabens in the basement. Possibly some of these faults have been reactivated, producing displacements similar to those found within the Clarendon-Linden fault zone to the west.

Several features in figure E-15 are of particular interest. Two east-northeast trending features (A-A′ and B-B′ in the figure) appear to be faults bounding a down-dropped block. The apparent faults lie along major linear features on Landsat images, the Cortland-Ithaca and Watkins Glen-Taughannock lineament zones. Also of interest are the north and northeast trending structures (C-C′ in the figure) that outline the westernmost reentrant in the main 2 km contour of the magnetic basement (figure E-14). There is a suggestion that this reentrant, which is located between longitudes 77°30′ W and 76° 45′ W, may be another failed rift similar to the Clarendon-Linden fault zone. Evidence for the rift is contained in the aeromagnetic map, which shows notable symmetry about the axis of the reentrant (figure E-16).

LINEAMENTS

Lineaments mapped from Landsat images are superimposed on the magnetic basement in figure E-17. Many of the lineaments can be correlated with apparent changes in slope of the magnetic basement. Other lineaments lie along magnetic basement ridges. The northeast-trending Cortland-Ithaca lineament zone (Ct-It), for example, is underlain by basement ridges along part of its length, but is elsewhere correlated with apparent down-faulting of the basement to the northwest. The parallel Watkins Glen-Taughannock lineament zone (WG-Ta) is apparently correlated with a basement fault that is downthrown to the southeast. This sense of motion agrees with seismic evidence given in appendix F, which indicates down-faulting to the southeast with 80 ft of displacement on top of the Trenton limestone.

The Van Etten-Candor lineament (VE-Ca) appears to be associated with sloping or downfaulting of the basement to the south. The Van Etten-Towanda (VE-To) and Van Etten-Oddessa

(VE-Od) lineaments appear to be associated with faulting or sloping of the basement away from the Van Etten dome. The down-to-the-west character of the basement along the Van Etten-Towanda lineament is also evident along the extension of this lineament to the north.

The longer north-northwest trending lineaments, which are perpendicular to the fold axes of the Paleozoic sediments, are most likely tear faults resulting from thin-skinned tectonic deformation (Podwysocki and others, 1979). Correlation of basement features with the Van Etten-Towanda lineament suggests that the locations of tear faults can be controlled in part by sub-decollment structure.

The northwest trending Corning-Bath lineament (Cr-Ba) appears to be related to to magnetic basement topography, but it cannot be explained by a consistent vertical displacement of the basement surface. Therefore, like the northwest trending structures interpreted from aeromagnetic data in westernmost New York, the Corning-Bath lineament may be related to a shear zone within the basement.

GRAVITY DATA

The Bouguer gravity map of western New York (Revetta and Diment, 1971) has been compared to the available aeromagnetic maps. Although north and northeast trends are present in both data sets, the gravity anomalies show little direct correlation with the magnetic anomalies.

A comparison of aeromagnetic data (eg. USGS, 1978, 1954) and gravity data (Simmons and Diment, 1973) with the exposed crystalline rocks of the Adirondacks (New York State Museum and Science Service, 1971) reveals that large intense positive magnetic anomalies are produced by granitic gneiss, whereas less intense large positive magnetic anomalies are produced by granitic gneiss and metasedimentary gneiss. Small (approximately 1 km wavelength) intense positive magnetic anomalies are produced by metagabbroic plutons. Large gravity lows are seen over extensive bodies of meta-anorthosite and anorthositic gneiss. Gravity highs occur over charnockitic, granitic and quartz syenitic gneisses and associated quartz-feldspar gneisses. The gabbro bodies are generally too small to be seen in the regional gravity anomaly map.

Gravity anomalies in central and western New York are likely to be influenced by varying densities within the sedimentary section. In particular, significant variations in the thickness of low density salt should produce observable gravity anomalies. In support of this contention is the fact that the lowest gravity values in western New york occur near Waverly, directly over the thickest part of the "F Salt" unit of the Upper Silurian Salina Group (Rickard, 1969). The Waverly gravity low covers a large area which is roughly the area of overthickened "F Salt". Thus it is possible that the gravity anomaly map may be very sensitive to the total salt thickness. For a more extensive interpretation of regional gravity anomalies in terms of basement tectonics, the reader is referred to Diment and others (1980).

CONCLUSIONS

A quantitative study of aeromagnetic data for central and western New York has revealed numerous basement structures, one or two of which can be interpreted as being failed Precambrian rifts. The best defined of these apparent rifts lies along the Clarendon-Linden fault zone in western New York. Another possible rift is located 100 km to the east of the Clarendon-Linden structure. Aeromagnetic anomalies display some degree of bilateral symmetry over these features. Depth estimates made from the aeromagnetic data clearly show depression of the magnetic basement within the apparent rift zones. The depth estimates also help locate the border faults. Limited deep-well data suggest that the relief on the crystalline basement over the apparent rift zones is much less than the relief on the magnetic basement, a situation that would arise if the former rift fill material had been altered to metasediment. In addition to the apparent rifts, the magnetic depth estimates reveal other inferred basement faults as well as broader topographic features such as ridges and domes.

Seismic activity along the Clarendon-Linden fault zone (Fletcher and Sykes, 1977) indicates that basement faults may be reactivated under the present-day compressive stress regime. A high degree of correlation is seen between magnetic basement structures and surface lineaments in south-central New York, which suggests that at least part of the surface topography and drainage pattern in this area may be controlled by reactivated basement faults. In particular, northwest-trending lineaments appear to be associated with basement shear faults, whereas east-northeast trending lineaments appear to correspond to vertical faults in the basement. North-northwest trending lineaments are perpendicular to the Appalachian fold axis and most likely represent tear faults that were produced during Appalachian decollement thrusting. There is some suggestion in the aeromagnetic data that the locations of these tear faults are also controlled by basement structures.

REFERENCES

Burke, K., 1980, Intracontinental rifts and aulacogens in Continental Tectonics, Nat. Acad. Sci., Washington, D.C.

Bhattacharyya, B. K., 1965, Two-dimensional harmonic analysis as a tool for magnetic interpretation, Geophysics, 30, 829-857.

Diment, W. H., O. H. Muller and P. M. Lavin, 1980, Basement tectonics of New York and Pennsylvania as revealed by gravity and magnetic studies; in The Caledonides in the U.S.A. (Wones, D. R., ed), Proceedings of 1979 Project 27 Meeting, Department of Geological Sciences, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 221-227.

Eaton, G. P., Wahl, R. R., Prostka, H. J., Mabey, D. R., and Kleinkopf, M. D., 1978, Regional gravity and tectonic patterns: Their relation to late Cenozoic epeirogeny and lateral spreading in the western Cordillera in Cenozoic Tectonics and Regional Geophysics of the Western Cordillera, (Smith, R. B., and Eaton, G. P., eds.), Geol. Soc. America Mem. 152, 51-91.

Fletcher, J. B., and L. R. Sykes, 1977, Earthquakes related to hydraulic mining and natural seismic activity in western New York State, J. Geophys. Res., 82, 3767-3780.

Kreidler, W. L., 1959, Selected deep wells and areas of gas production in eastern and central New York, N. Y. State Museum and Science Service Bull. 373.

______________, 1963, Selected deep wells and areas of gas production in western New York, N. Y. State Museum and Science Service Bull. 390.

Kreidler, W. L., A. M. Van Tyne and K. M. Jorgensen, 1972, Deep wells in New York State, N. Y. State Museum and Science Service Bull. 418A.

Martens, J. H. C., 1924, Igneous rocks of Ithaca, New York and vicinity, G. S. A. Bull., 35, 305-320.

New York State Museum and Science Service, 1971, Geologic map of New York, Adirondack sheet, Map and chart series no. 15.

Phillips, J. D., 1979, Adept: a program to estimate depth to magnetic basement from sampled magnetic profiles, U. S. Geol. Survey Open-file report 79-367.

Podwysocki, M. H., H. Pohn, I. S. Merin, D. Krohn, J. D. Phillips and L. C. Rowan, 1979, Evidence for dual mechanisms of deformation in south central New York and north central Pennsylvania (abs.), G. S. A. Abstracts with Programs, 11(1).

Revetta, F. A., and W. H. Diment, 1971, Simple Bouguer gravity anomaly map of western New York, N. Y. State Museum and Science Service, Map and Chart Series No. 17.

Rickard, L. V., 1969, Stratigraphy of the Upper Silurian Salina Group, New York, Pennsylvania, Ohio, Onterio; New York State Museum and Science Service, Geological Survey, Map and Chart Series No. 12, 57p, 14 plates.

______________, 1973, Stratigraphy and structure of the subsurface Cambrian and Ordovician carbonates of New York, New York State Museum and Science Service, Geological Survey, Map and Chart Series No. 18, 25 p., 19 plates.

Sbar, M. L., and L. R. Sykes, 1973, Contemporary compressive stress and seismicity in eastern North America: An example of intra-plate tectonics, Geol. Soc. Amer. Bull., 84, 1861-1882.

Simmons, G., and W. H. Diment, 1973, Simple Bouguer gravity anomaly map of northern New York, N. Y. State Museum and Science Service, Map and Chart Series No. 17A.

U. S. Geological Survey, 1954, Total intensity aeromagnetic and geologic map of Cranberry Lake quadrangle, New York, U. S. G. S. Map G. P. 118.

______________________, 1975, Aeromagnetic map of westernmost New York, U. S. Geol. Survey Open-file Report 75-28, scale 1:250,000.

______________________, 1978, Aeromagnetic map of the eastern part of the Adirondacks mountains, New York, U. S. Geol. Survey Open-file Report 78-279.

______________________, 1979, Aeromagnetic survey of central New York, U. S. Geol. Survey Open-file Report 79-653, scale 1:250,000.

Van Tyne, A. M., 1975, Clarendon-Linden Structure, western New York, N. Y. State Geol. Survey open file report.

Vine, F. J., and Wilson, J. T., 1965, Magnetic anomalies over a young oceanic ridge off Vancouver Island, Science, 150, 485-489.

Wallace, L. G., and W. deWitt, Jr., 1975, Maps showing selected deep wells drilled foe oil or gas in the Appalachian Basin, U. S. Geol. Survey Misc. Investigations Series Map I-936, scale 1:1,000,000.

Zartman, R. E., Brock, M. R., Heyl, A. V., and Thomas, H. H., 1967, K-Ar and Rb-Sr ages of some alkalic intrusive rocks from central and eastern United States, Am. Jour. Sci., 265, 848-870.

FIGURE CAPTIONS

Figure E-1 -- Aeromagnetic map for westernmost New York (USGS, 1975). The contour interval is 200 nT.

Figure E-2 -- A detail of the aeromagnetic map with line segments connecting corrésponding anomalies across a line of symmetry. The midpoints of the line segments define a possible axis of rifting. Dashed lines bound the Clarendon-Linden fault zone (Van Tyne, 1975).

Figure E-3 -- The second vertical derivative of the aeromagnetic map for westernmost New York. Only the zero contour is shown, with black defining positive anomalies.

Figure E-4 -- A lithologic interpretation of the second vertical derivative map. Dark areas define strongly magnetic plutons. Lighter areas define magnetic bodies of lower intensity.

Figure E-5 -- A structure contour map of the crystalline basement based on deep wells (closed circles). The contours are in km below sea level. The Clarendon-Linden fault system is also shown (after Van Tyne, 1975).

Figure E-6 -- Magnetic basement contours as interpreted from the aeromagnetic map. Depths are relative to sea level. Only the 1 km and 2 km contours are shown. The Clarendon - Linden fault system is superimposed on the figure.

Figure E-7 -- Locations of magnetic depth estimates falling in the range 0 to 3 km below sea level. Aligned depth estimates may define linear basement structures.

Figure E-8 -- Linear basement structures as interpreted from the locations of magnetic depth estimates.

Figure E-9 -- Aeromagnetic map of central New York (USGS, 1979). The contour interval is 200 nT. Color coding of the contour intervals is the same an in figure E-1.

Figure E-10 -- The second vertical derivative of the aeromagnettc map for central New York. Only the zero contour is shown, with black defining positive anomalies.

Figure E-11 -- A lithologic interpretation of the second vertical derivative map. Shaded areas indicate magnetic lithologies. The wide stipple pattern defines a possible reversely magnetized pluton.

Figure E-12 -- A structure contour map of the crystalline basement as based on deep wells (closed circles). The contours are in km below sea level.

Figure E-13 -- Magnetic basement contours as interpreted from the aeromagnetic data. Depths are relative to sea level. Only the 0 km, 1 km, 2 km and 3 km contours are shown. Contour interval shading is the same as in figure E-6.

Figure E-14 -- Locations of magnetic depth estimates falling in the range 0 to 4 km below sea level. Aligned depth estimates may define linear basement structures.

Figure E-15 -- Linear basement structures as interpreted from the locations of magnetic depth estimates.

Figure E-16 -- A detail of the aeromagnetic map with line segments connecting corresponding anomalies across a line of symmetry. The midpoints of the line segments define a possible axis of rifting.

Figure E-17 -- Mapped surface lineaments in central New York superimposed on the magnetic basement contours.

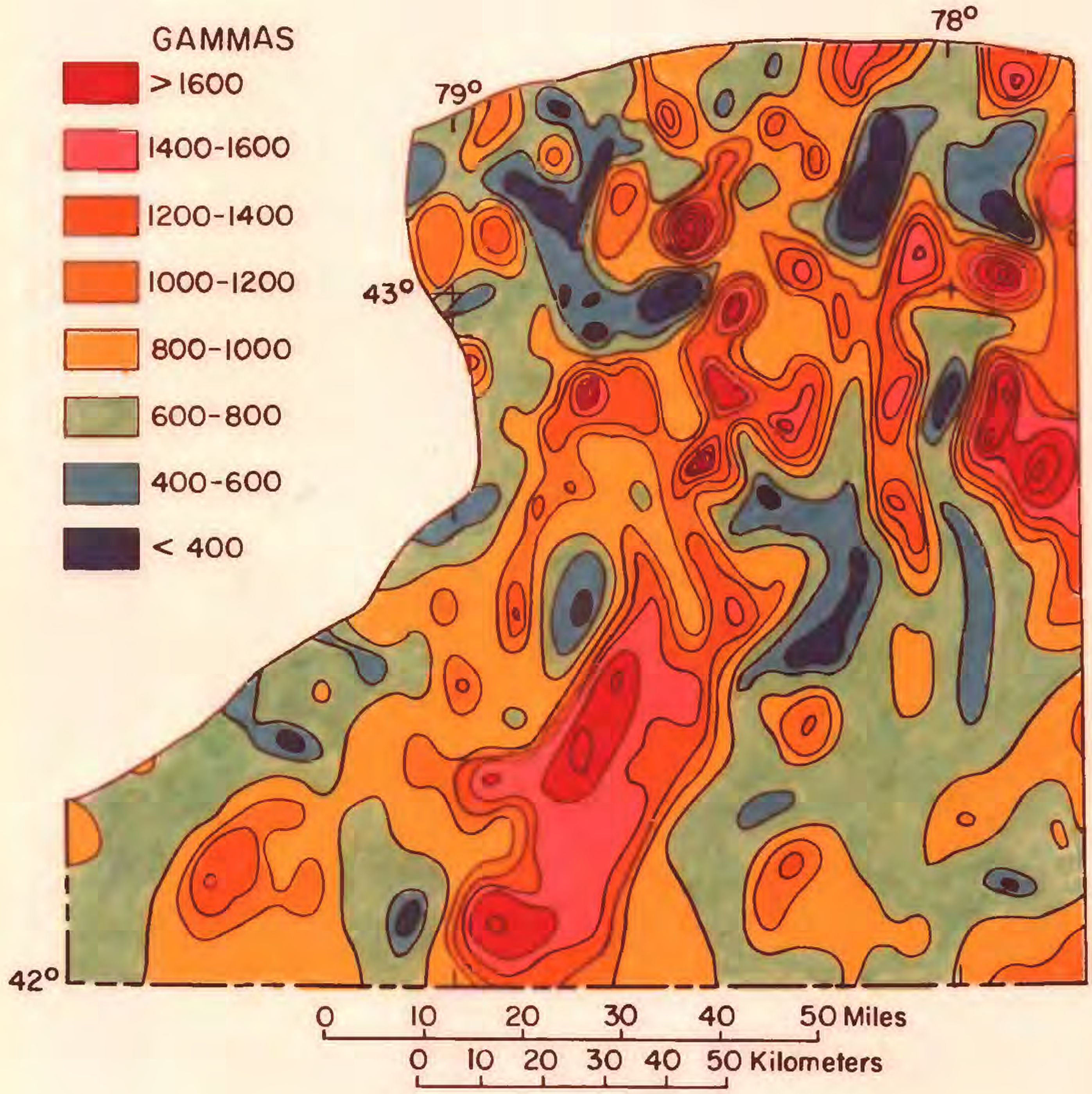

GAMMAS
> 1600
1400-1600
1200-1400
1000-1200
800-1000
600-800
400-600
< 400
78°
79°
43°
42°
0 10 20 30 40 50 Miles
0 10 20 30 40 50 Kilometers

Figure E-1

Figure E-2

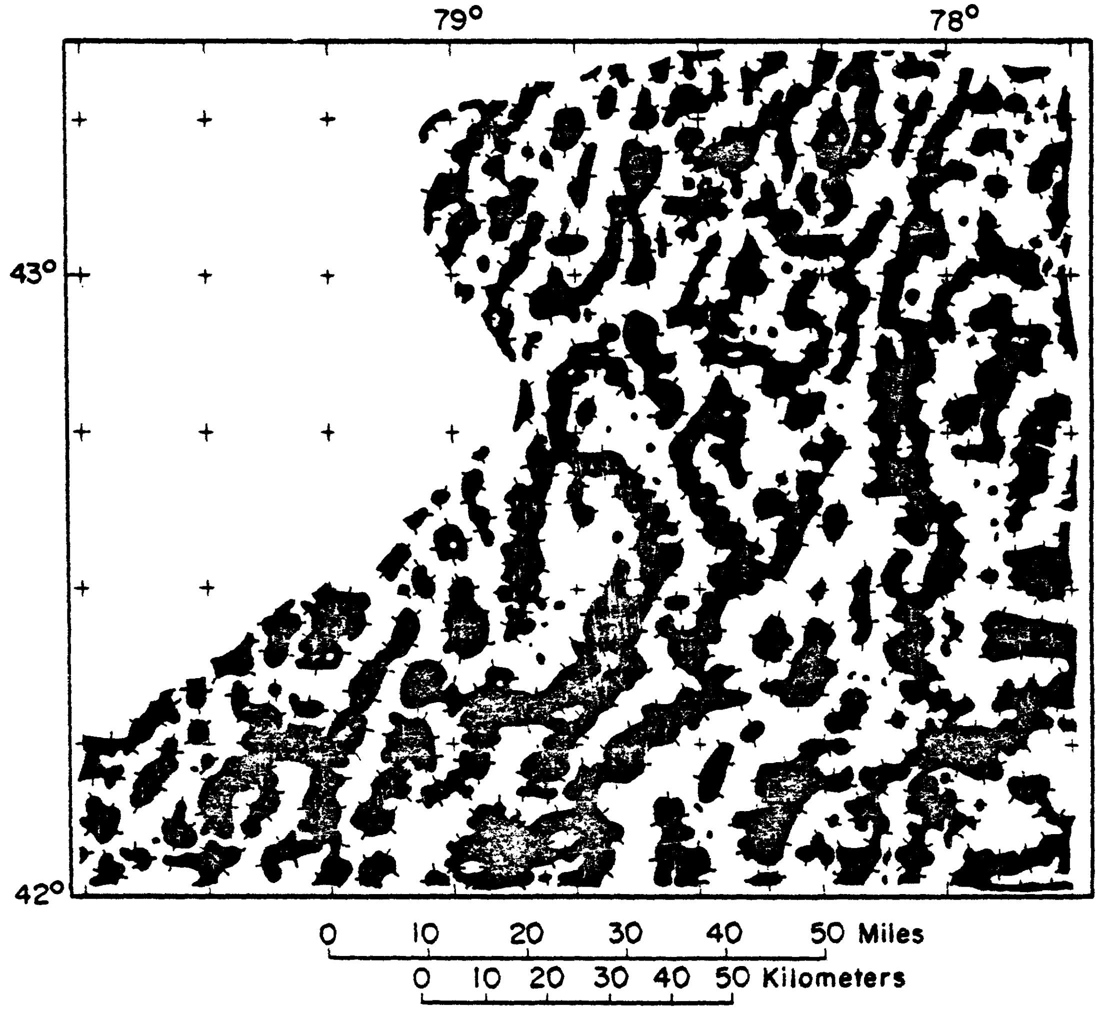


Figure E-3

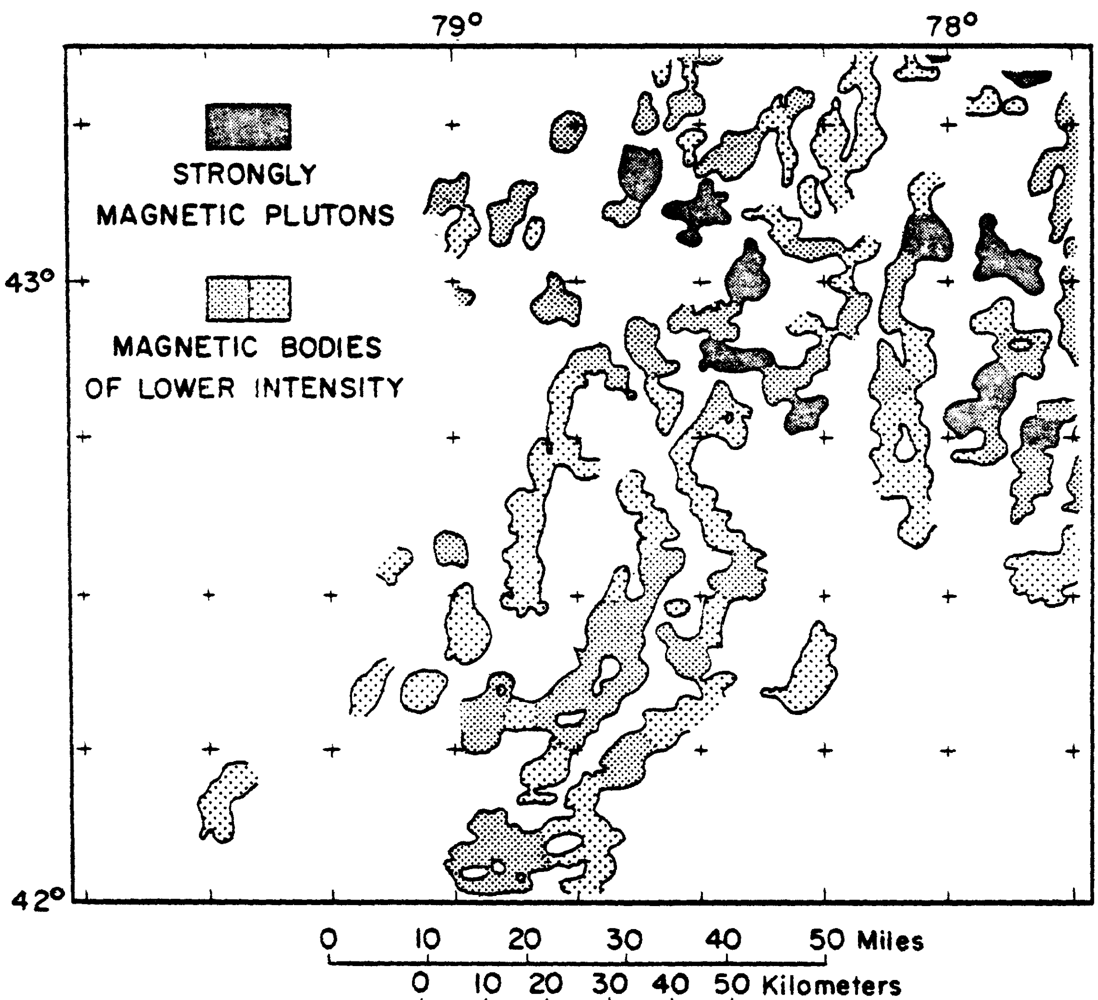
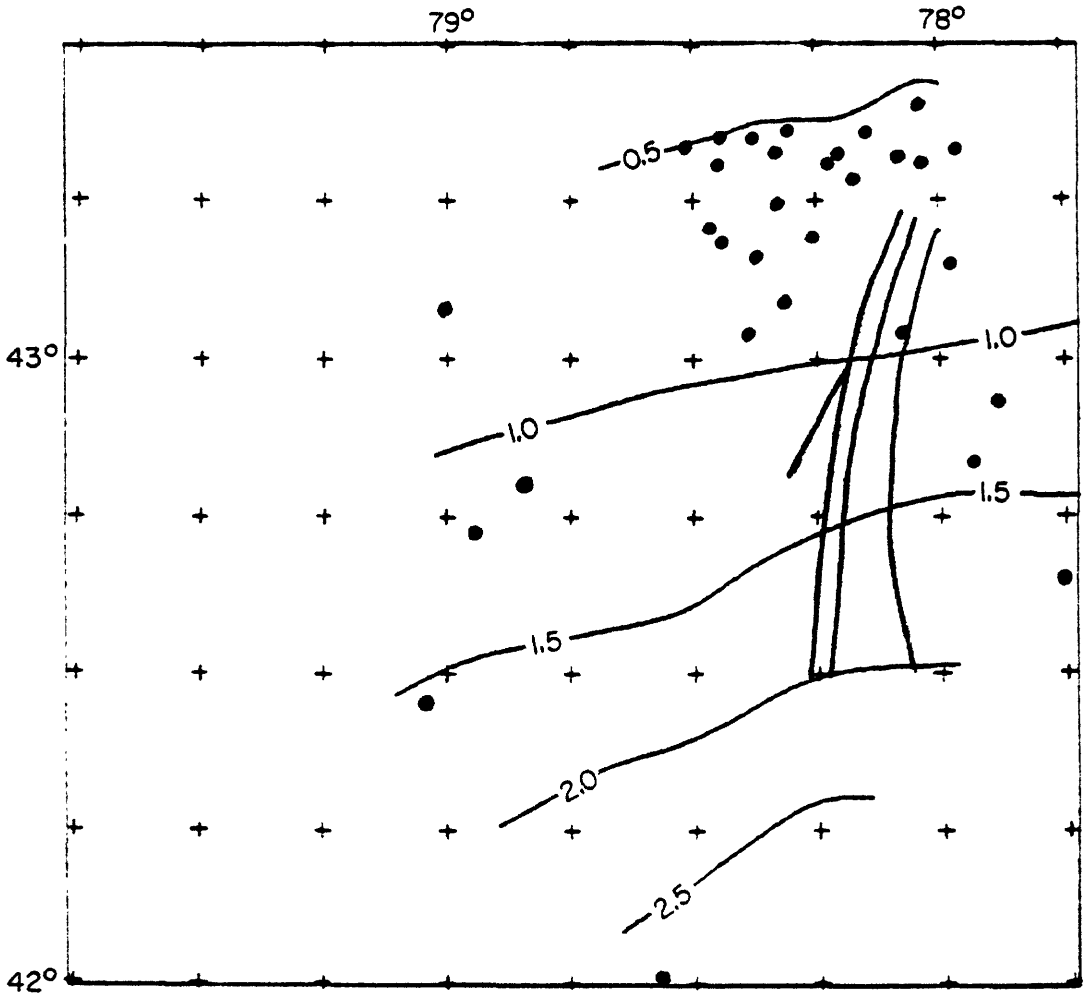

79°
78°
STRONGLY
MAGNETIC PLUTONS
MAGNETIC BODIES
OF LOWER INTENSITY
43°
42°
0 10 20 30 40 50 Miles
0 10 20 30 40 50 Kilometers

Figure E-4



0 10 20 30 40 50 MILES

0 10 20 30 40 50 KILOMETERS

Figure E-5

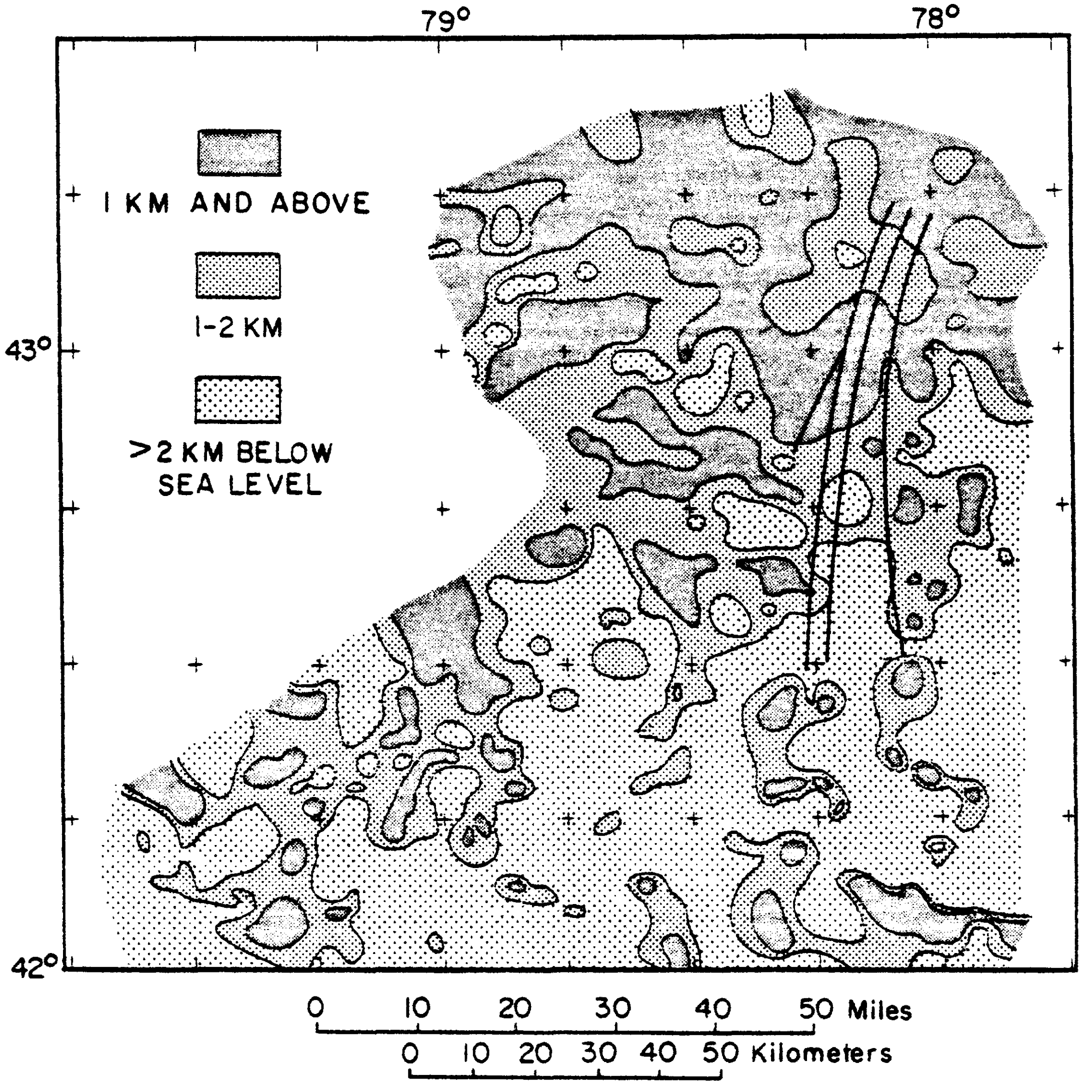

79°
78°
43°
42°
1 KM AND ABOVE
1-2 KM
>2 KM BELOW
SEA LEVEL
0 10 20 30 40 50 Miles
0 10 20 30 40 50 Kilometers

Figure E-6

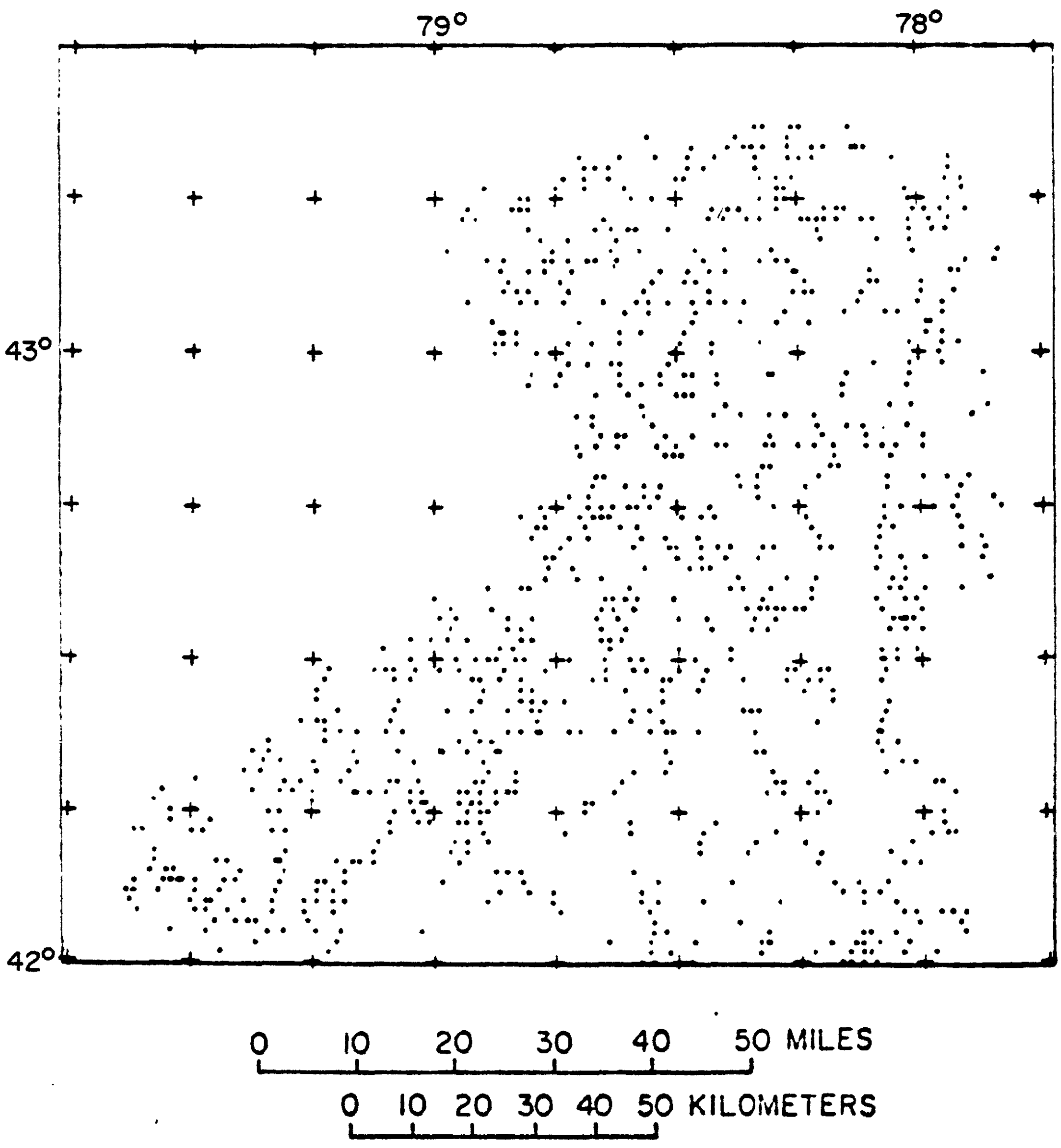
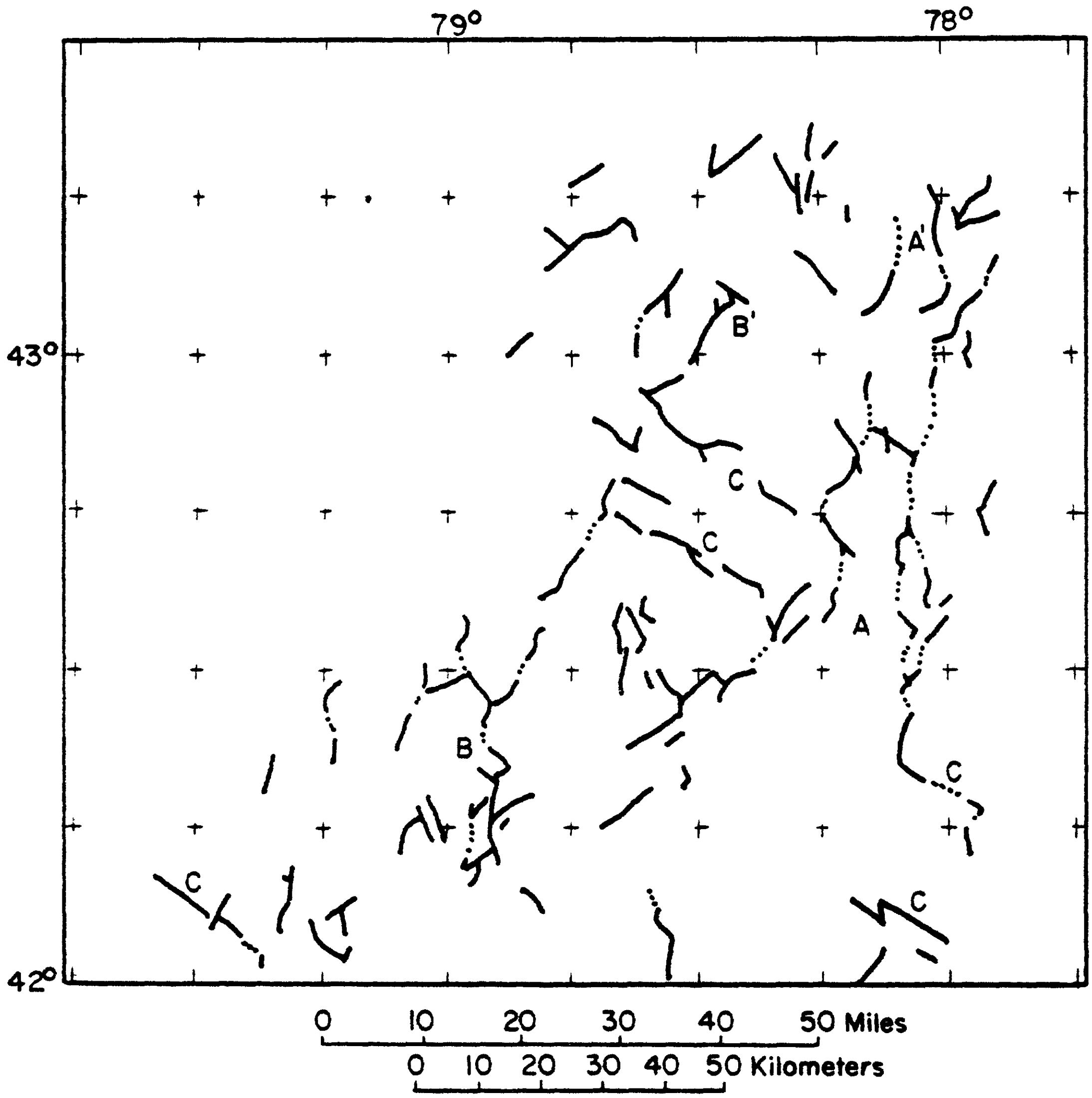


Figure E-7



79°
78°
43°
42°
A'
B'
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C
A
B
C
C
C
0 10 20 30 40 50 Miles
0 10 20 30 40 50 Kilometers

Figure E-8

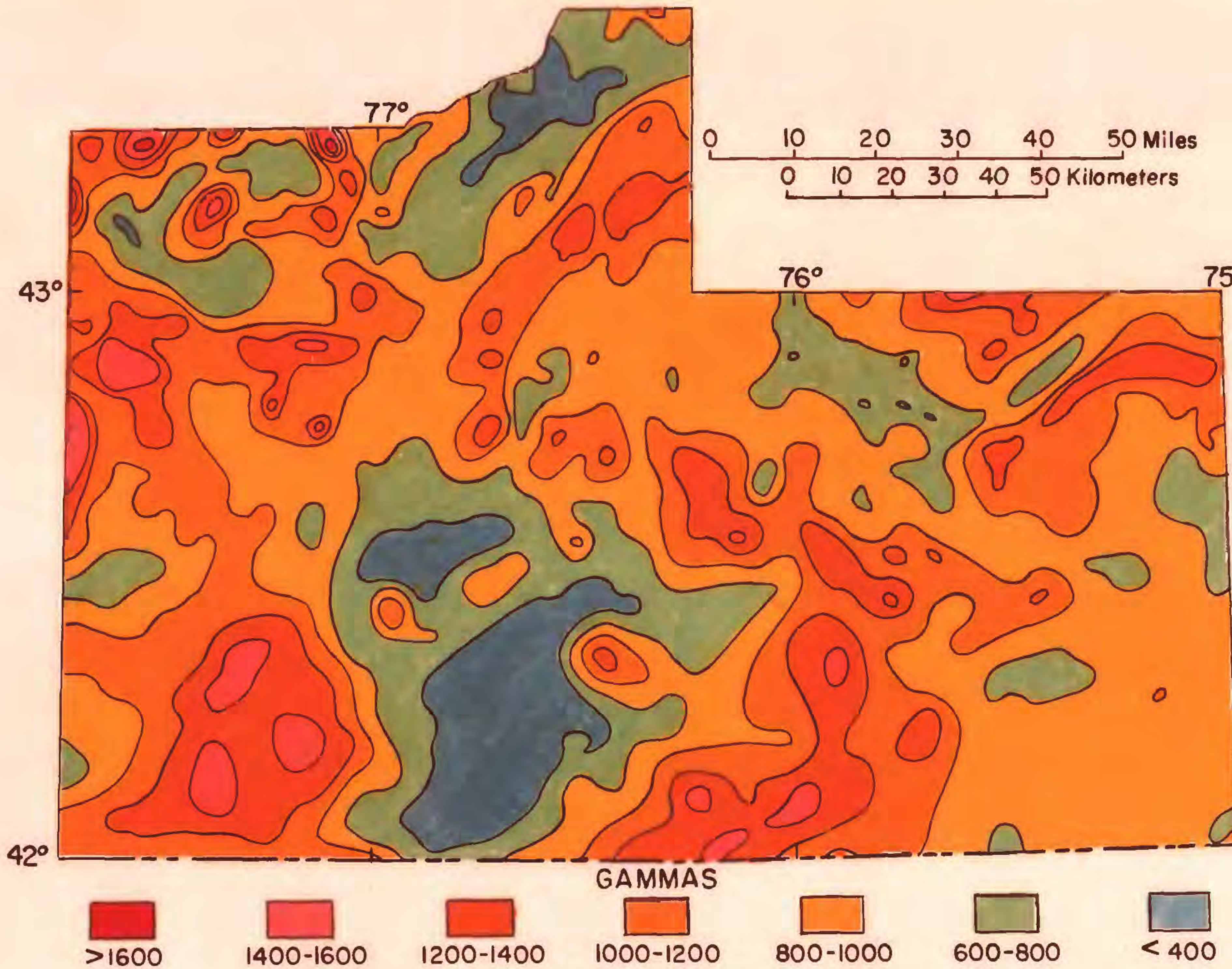

77°
76°
75°
43°
42°
0 10 20 30 40 50 Miles
0 10 20 30 40 50 Kilometers
GAMMAS
>1600
1400-1600
1200-1400
1000-1200
800-1000
600-800
< 400

Figure E-9

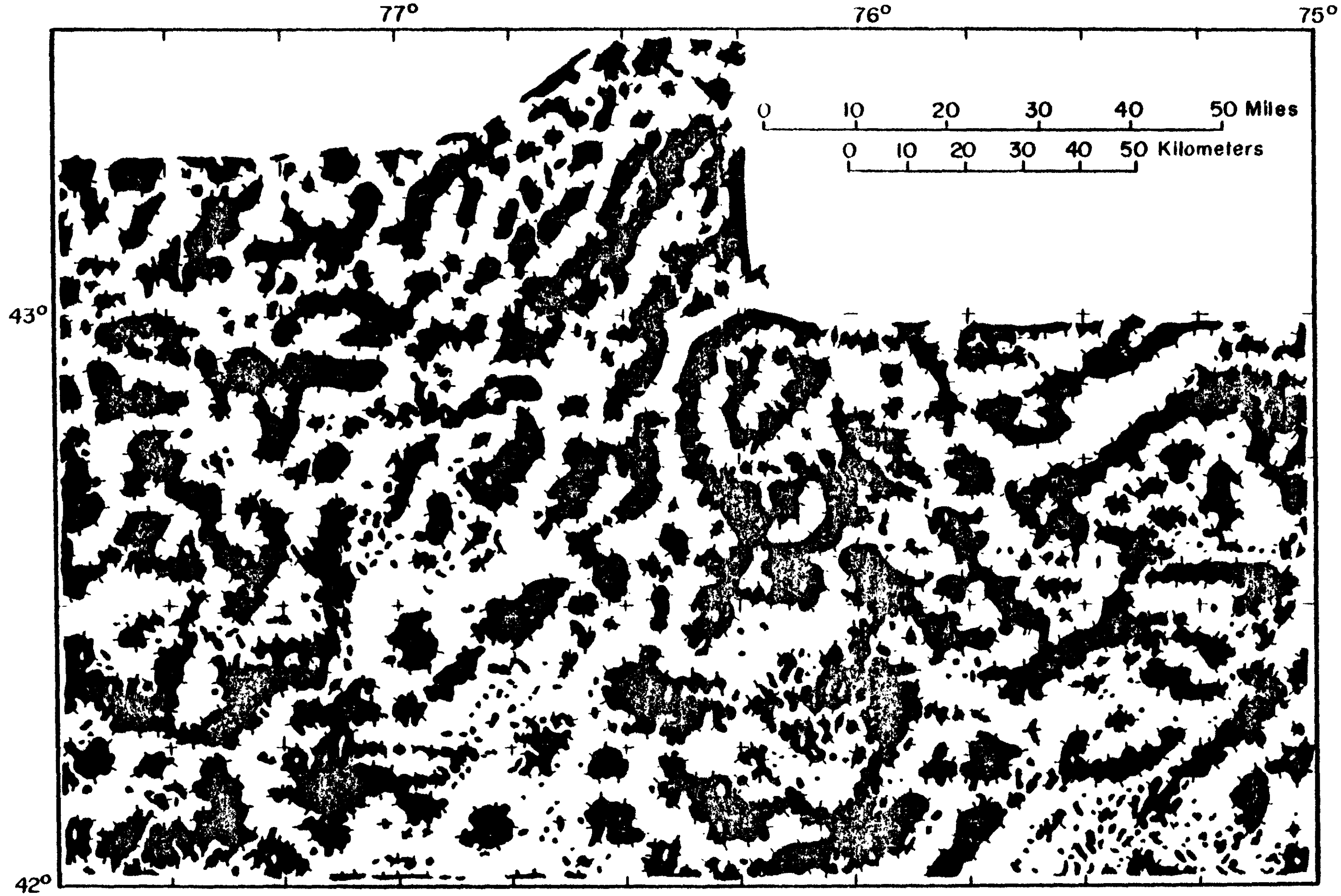


Figure F-10

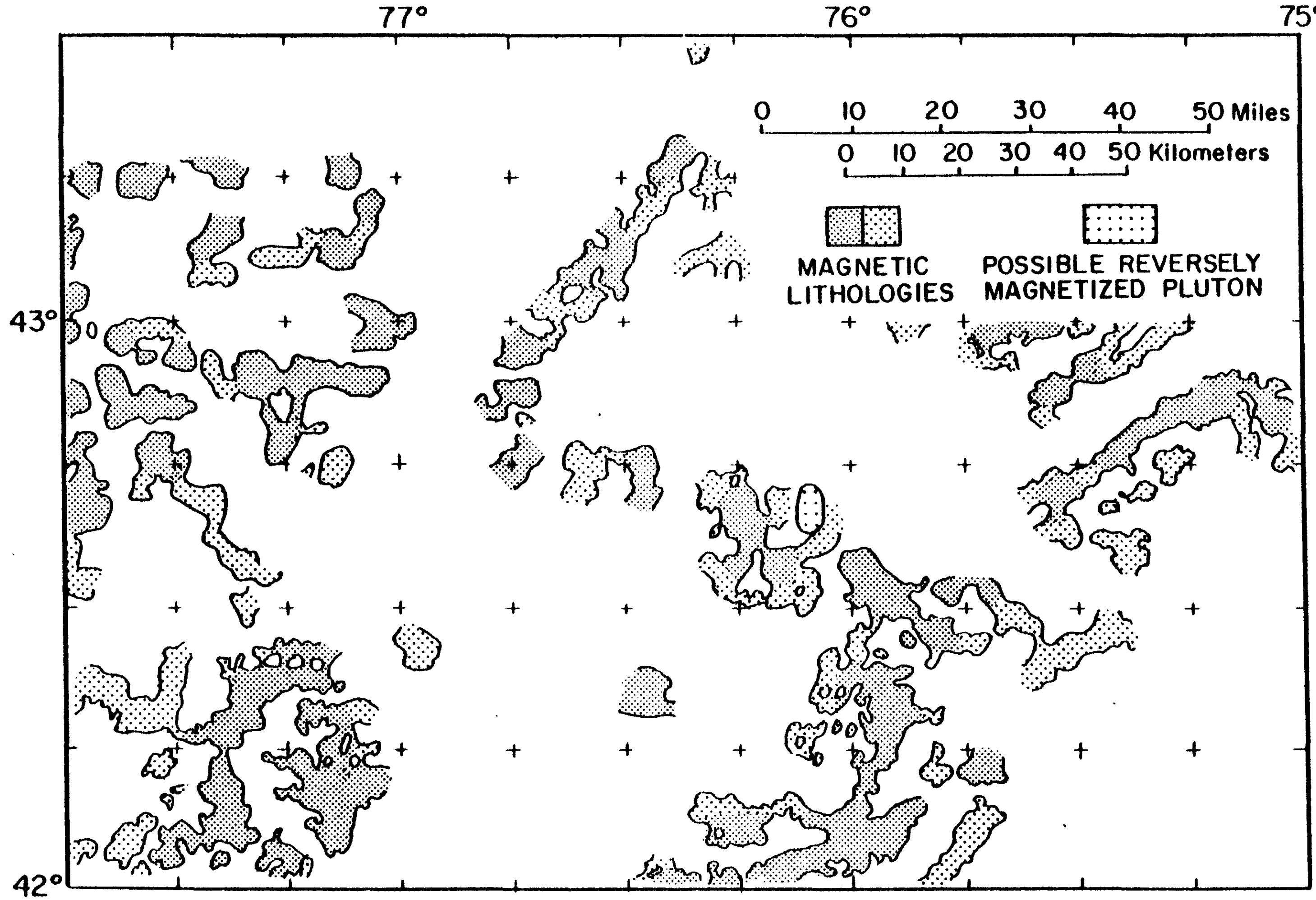
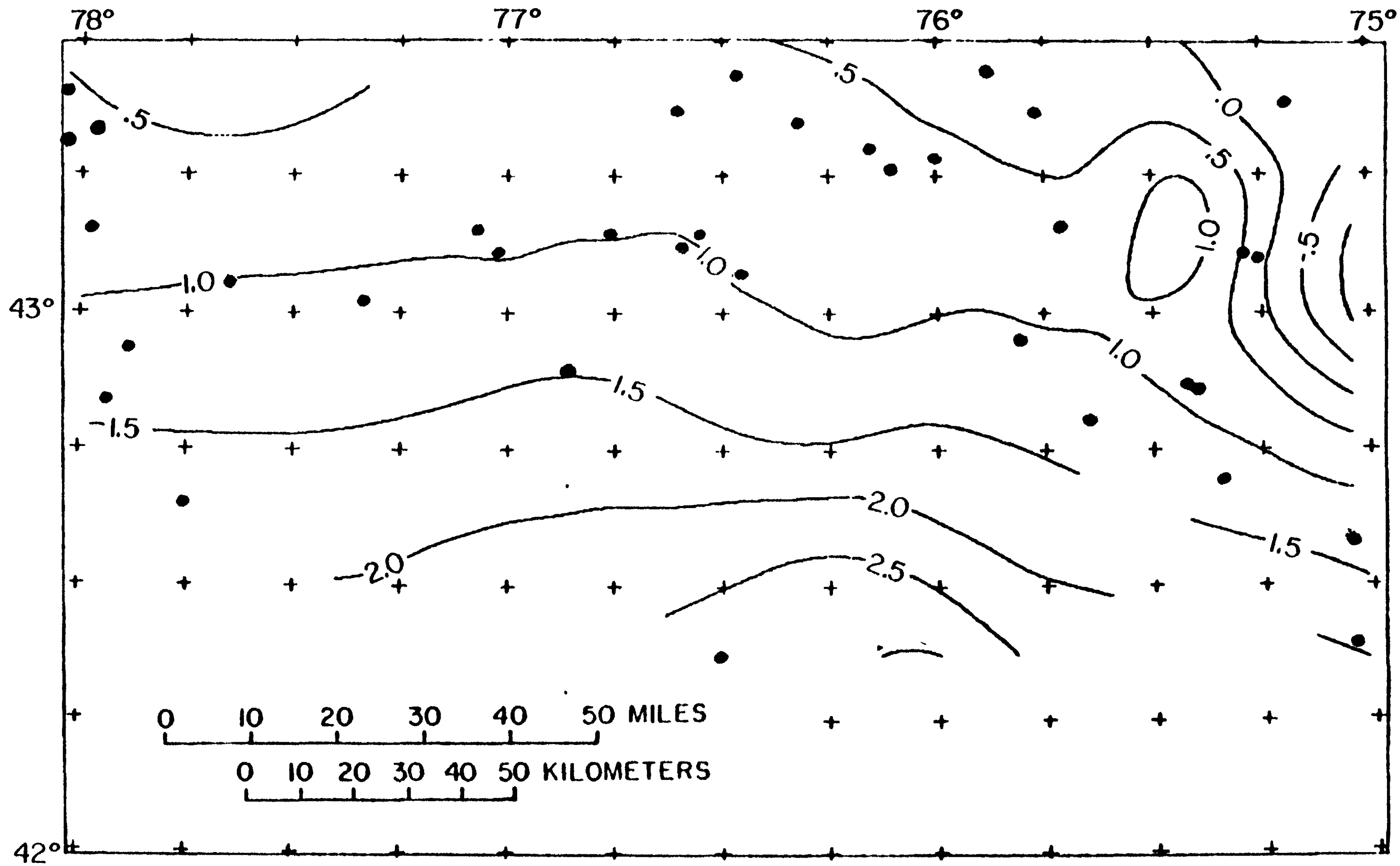

77°
76°
75°
43°
42°
0 10 20 30 40 50 Miles
0 10 20 30 40 50 Kilometers
MAGNETIC
LITHOLOGIES
POSSIBLE REVERSELY
MAGNETIZED PLUTON

Figure F-11


78°
77°
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43°
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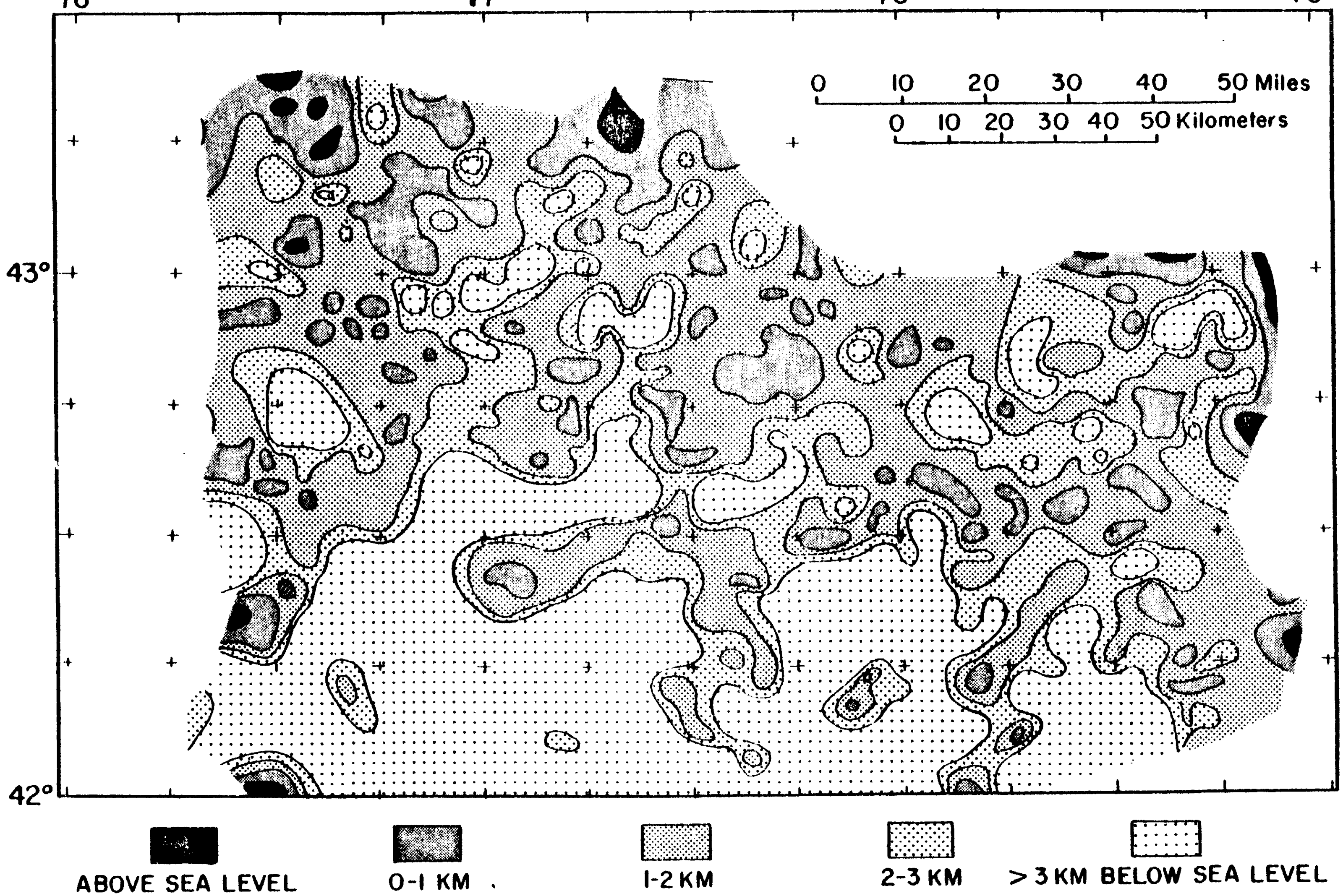
.5
1.0
1.5
2.0
2.5
0 10 20 30 40 50 MILES
0 10 20 30 40 50 KILOMETERS

Figure F-12



0 10 20 30 40 50 Miles
0 10 20 30 40 50 Kilometers
43°
42°
ABOVE SEA LEVEL
0-1 KM
1-2 KM
2-3 KM
> 3 KM BELOW SEA LEVEL

Figure E-13

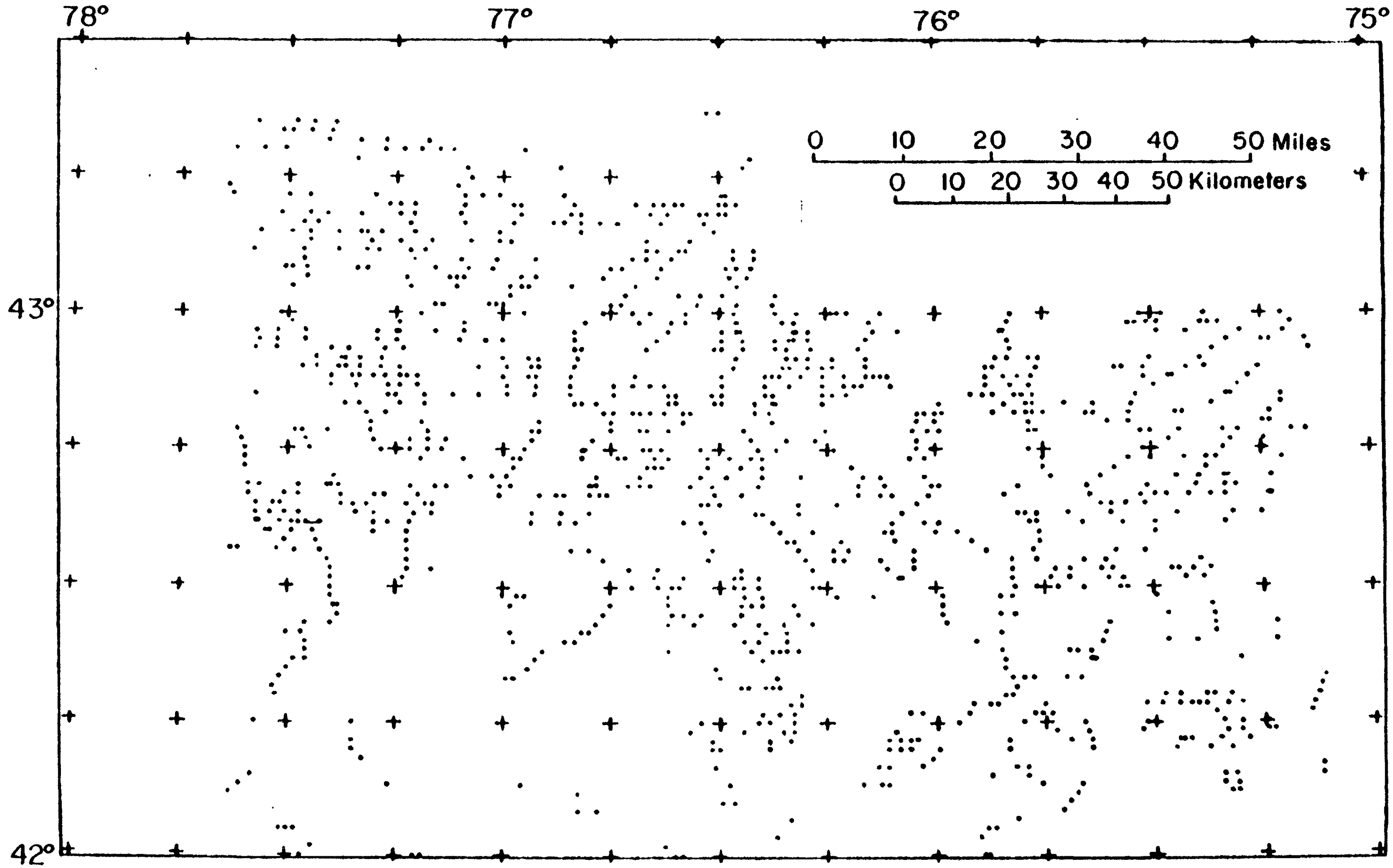


Figure E-14

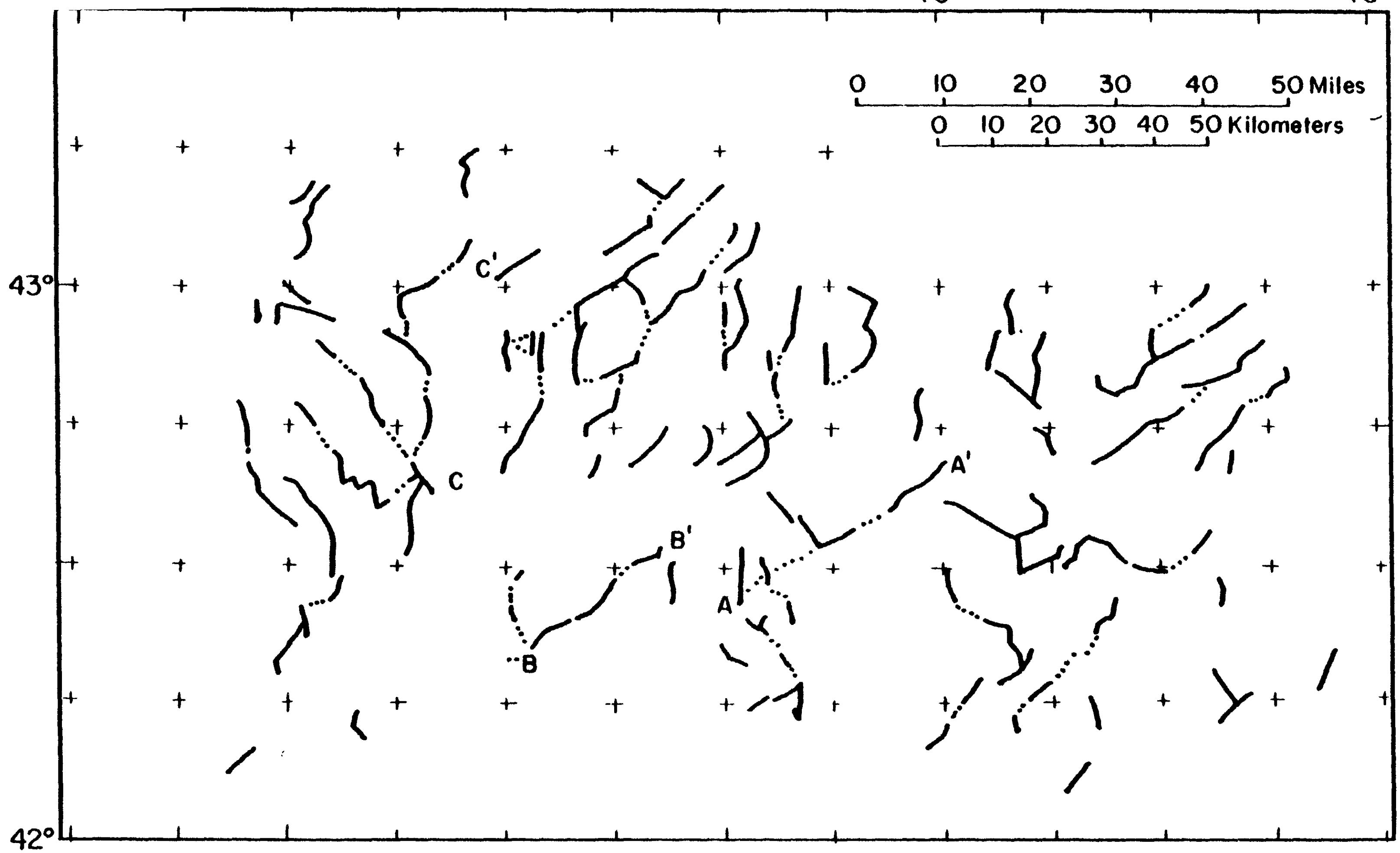


Figure F-15

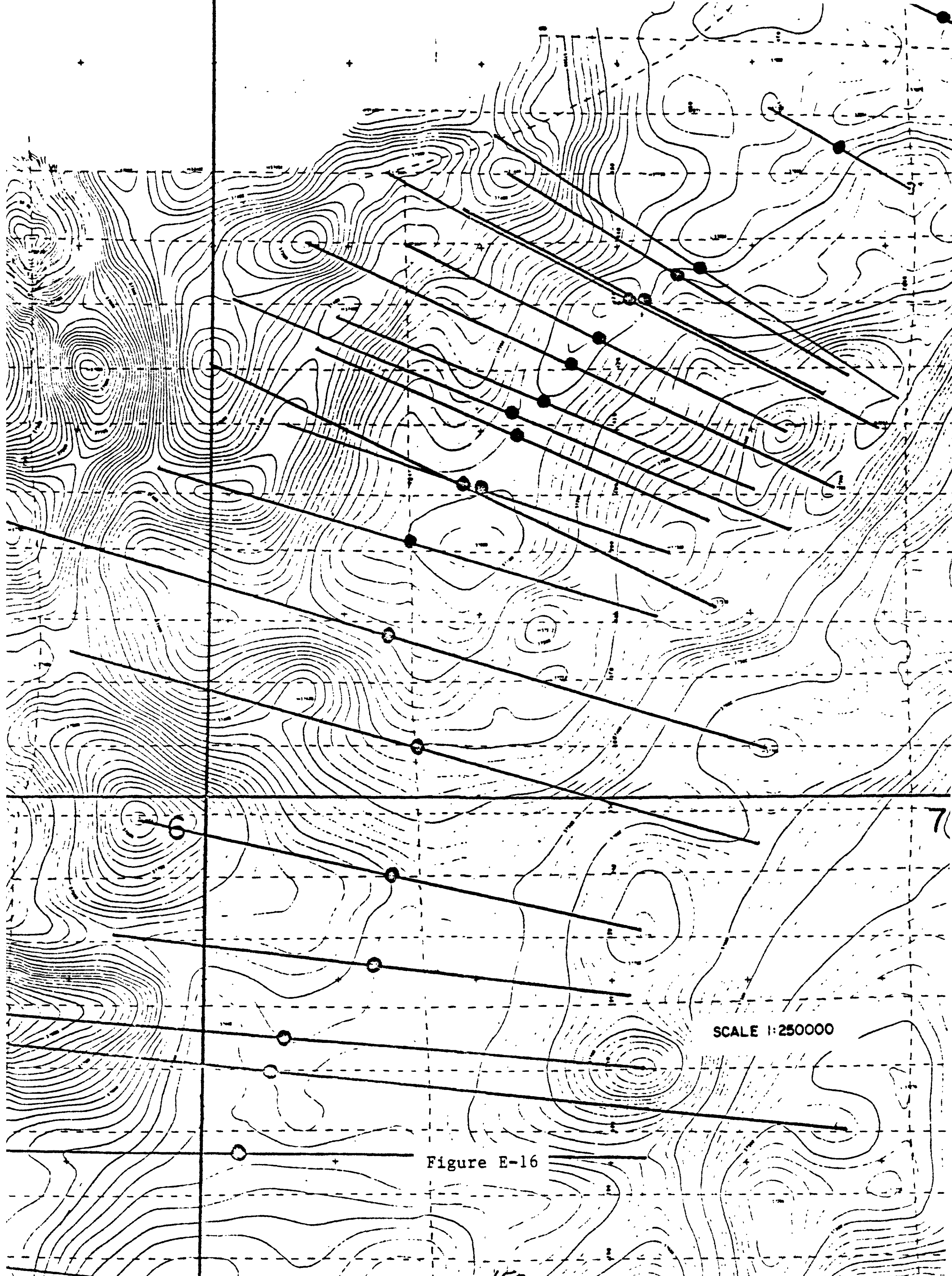


Figure E-16

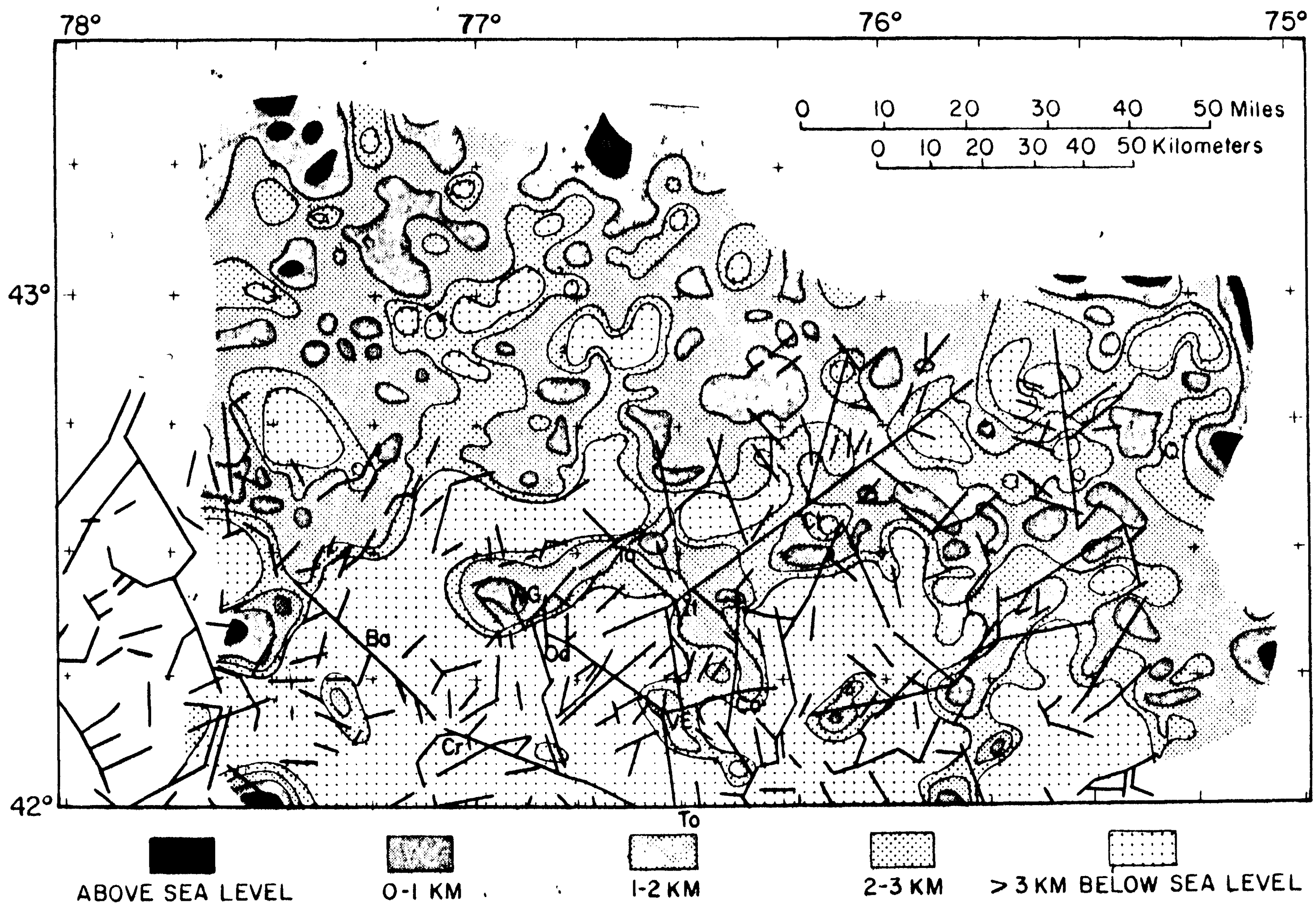

78°
77°
76°
75°
43°
42°
0 10 20 30 40 50 Miles
0 10 20 30 40 50 Kilometers
Ba
Cr
To
ABOVE SEA LEVEL
0-1 KM
1-2 KM
2-3 KM
>3 KM BELOW SEA LEVEL

Figure E-17

APPENDIX F: ANALYSIS OF SEISMIC DATA

This appendix presents geologic interpretations of seismic reflection data for south-central New York State. The data themselves are proprietary, being the property of various oil and gas companies.

INTERPRETED SEISMIC SECTIONS

Woodhull Structure

Figure F-1 presents an interpretation of a blinded (unlabeled) seismic reflection profile across the Woodhull anticline in south-central Steuben County, N.Y. This is the most dramatic structural feature revealed in our study area, and it may be typical of other faulted anticlines in northern Pennsylvania and south-central New York. The shallowest reflector in the section is the Devonian Tully Limestone. Deeper reflectors include the Devonian Onondaga Limestone and the Silurian Lockport Dolomite. Salt units of the Silurian Salina Group are located between these latter two reflectors. Two faults are drawn in figure F-1, bordering a small graben on the south limb of the anticline. The interpretation is that the salt under the anticlinal crest has been overthickened as a result of underthrusting from the south and flowage of salt from beneath the graben into the adjacent regions. The northern thrust fault rises from a decollement surface near the top of the Lockport Dolomite. An apparent fault on the Lockport Dolomite may be responsible for the location of the thrust.

Ithaca - Danby Area

Landsat lineaments, taken from the compliations in the main body of this report, and seismic lines in the area of Ithaca, N.Y. are shown in figure F-2. The seismic lines were shot with a dynamite source and are of fair to poor quality.

An interpretation based on line A (figure F-3) shows a characteristic section with little structure. In addition to the major carbonate units, reflectors are sometimes seen above the Tully Limestone and are always seen within the Salina Group, which lies between the Onondaga Limestone and the Lockport Dolomite. Continuous reflectors are never seen between the Lockport Dolomite and the Ordovician Trenton Limestone. The deepest reflector is probably the Cambrian Theresa Dolomite, which acts as the acoustic basement. Below the Tully Limestone, the section displays a gradual southward dip, which steepens slightly to the south of shot-point 8. Under shot-point 24, there is some evidence of a flexure in the Theresa Dolomite accompanied by anticlinal warping of the overlying units. The Tully Limestone appears to have vertical discontinuities, but these are not seen in the deeper units, and if real, they suggest a decollement above the Onondaga Limestone. There are no mapped lineaments crossing line A, which is consistent with the structural simplicity of the section.

Two other north-south lines (lines B and C in figure F-2) appear to cross a northeast-trending fault that does not lie along a mapped lineament. The locations of the fault crossings are shown by the circles in figure F-2. A weakly expressed lineament does cross both lines, but it has the wrong orientation and location to fit the fault observed in lines B and C. The fault appears on the Lockport Dolomite and the Trenton Limestone and is downthrown to the north. The absence of a corresponding lineament may indicate that the fault does not extend above the salt.

Another fault was crossed by a single line (line D, figure F-2). In our interpreted section for this line (figure F-4) the fault is located between shot-points 6 and 7. The Theresa Dolomite and Trenton Limestone are clearly down to the east, whereas the Lockport Dolomite and Onondaga limestone appear to be up to the east. The Tully Limestone may be folded rather than faulted. The fault is located at the intersection of line D with a mapped lineament (circle in figure F-2), which runs along Buttermilk Creek, south of Ithaca, N.Y., and may connect with another lineament along the western side of Cayuga Lake. The implication is that Buttermilk Creek and perhaps the western side of Cayuga Lake are controlled by a basement fault inferred from the seismic section. The reversed sense of displacement across the fault suggests multiple episodes of reactivation, with the reversal of movement perhaps indicating readjustment to different tectonic stress fields.

A final east-west line (line E, figure F-2) crosses a weakly expressed lineament near its eastern end. The interpreted section for this line is shown in figure F-5. No through-going fault is seen in the section. An offset in the Onondaga Limestone between shot-points 17 and 18 overlies a shallow syncline seen most clearly within the Salina Group and on the Trenton Limestone. It is unlikely that this slight fold is responsible for the weakly expressed lineament in figure F-2, because the lineament trends at right angles to the regional fold axis. Another possibility is that the offset and observed downwarp lie along the southwestern extension of the Cortland-Ithaca lineament.

Watkins Glen Area

Lineaments and seismic lines in the Watkins Glen area are shown in figure F-6. A Vibroseis* source was used for the profiles in this area, and they are of excellent quality. Our interpretation of line F (figure F-7) shows two areas of flexure. A small anticlinal flexure is present between shot-points 30 and 40 on all units below the Onondaga Limestone. A similar anticlinal flexure lies between shot-points 85 and 105. The Tully Limestone dissappears as the line descends into the Seneca Lake valley, and the record quality deteriorates. The Onondaga Limestone appears to be undisturbed throughout the section. No mapped lineaments cross this line.

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* Vibroseis is a Continental Oil Company trademark

The northeast-trending Watkins Glen-Taughannock lineament, running between the south end of Seneca Lake and the middle of Cayuga Lake, appears to have subsurface expression on three seismic lines (interpretations not shown for proprietary reasons). These are lines G and H in figure F-6 and north-south line I which crosses line G east of figure F-6. A fault breaks the Lockport Dolomite on lines I and G, but is not seen above the Trenton Limestone on line H. The fault is down to the southeast with approximately 24 meters of displacement on the Trenton Limestone. This fault is a gas prospect, the target being a dolomitized zone with in the Trenton Limestone which is apparently associated with a basement fault (R. Beardsley, Columbia Oil and Gas Corp., personal communication, 1980). Overlying units may sag into the depression left in the top of the Trenton Limestone by volume loss due to the dolomitization. Note that in figure F-6 the lineament is displaced about 1.5 km to the northwest of this subsurface fault. This may imply that movement on the fault was pre-Alleghenian, and that the trace of the fault was moved northward by Alleghenian deformation. The 1.5 km offset may provide a measure of the horizontal displacement along decollements in this area.

VAN ETTEN AREA

Seismic lines and linear valleys in the Van Etten area are shown in figure F-8. Van Etten lies at the center of a "Y" formed by the intersection of east, south, and northwest-trending linear valleys. The high quality Vibroseis profiles were recorded by a major oil company in 1972 and 1973, and were purchased by the USGS on a proprietary basis. Due to the relatively high density of data and the low structural relief, the interpretation is presented as travel-time contour maps rather than sections. Unit names assigned to the reflecting horizons are based on the known stratigraphy as recorded in the E. C. Kesselring #1 deep well near Van Etten (Kreidler, 1959, p.40), and on correlations with the other seismic profiles covered in this appendix. Although a proprietary velocity log was available for the J. Matejka, Jr. deep well, located southwest of Van Etten, these data were not purchased for this study.

Tully Limestone

The two-way travel-time contours (isochrons) on top of the Devonian Tully Limestone (figure F-9) are dominated by two domes, northeast and southwest of Van Etten. Both domes are gas prospects. The general structural trend is east-northeast, parallel to the Allegehenian folds. A northeast-trending syncline crosses the northwestern corner of the map and broadens to the north. The valleys to the south and northwest of Van Etten appear to overlie troughs in the immediate vicinity of the domes. The valley east of Van Etten is not clearly expressed. However, an east-west fold structure is seen to the north of this lineament. North of Van Etten this structure assumes the form of a slight depression on the Tully Limestone surface, and a faulted anticline on the underlying Onondaga Limestone surface (figure F-10). Just south of Spencer, this feature is expressed as a faulted anticline on the Tully Limestone surface.

Onondaga Limestone

Isochrons indicate that the Devonian Onondaga Limestone (figure F-10) is the most structurally complex unit seen in the seismic data, and the most highly faulted. Conformable in overall structure to the Tully Limestone, the Onondaga Limestone is domed to the southwest of Van Etten, and may also be domed to the northeast of Van Etten. The overall structural trend is east to east-northeast. There is a northeast-trending trough in the northwest corner of the area, directly underneath the same trough on the Tully Limestone. This trough may swing to the east and connect with a syncline north of Spencer.

The dominant structure on the Onondaga Limestone is a faulted anticline that trends east-west and whose axis is located 1.5 km north of Van Etten. At this location the axis of the anticline lies between, and parallel to conjugate thrust faults. To the east, near Spencer, the northern thrust fault is replaced by a high angle fault, and the graben formed between the two faults appears to lie to the south of the anticlinal axis.

Although there is some danger that the faulted anticline seen northwest of Van Etten may be partially a bow-tie effect produced by the overlying depression on the Tully Limestone surface, the similarity of this structure to the Woodhull anticline, the fact that the faults can be traced up through the section, and the fact that the underlying units are undisturbed suggest that this structure is real. In addition to the conjugate thrust faults, there are many other small faults seen on the Onondaga Limestone surface. One set appears to lie along the valley east of Van Etten, and may be responsible for the Van Etten-Candor lineament. Although several of these smaller faults can be traced upward to the base of the Tully Limestone, none can be traced below the Salina Group salts, which underly the Onondaga Limestone. This suggests that all of these faults are based in decollement surfaces within the salt units.

Lockport Dolomite

The isochron contours on top of the Silurian Lockport Dolomite (figure F-11) establish the pattern for units below the salt. Few faults are seen in these units, although it is possible to infer the presence of major faults along the north-south valleys. For example, the northeast-trending contours northwest of Spencer could be replaced in the interpretation by a fault trending along the linear valley north from Spencer. The sense of motion on this fault would be down to the east, and the fault would have to die out south of Spencer to explain the relatively flat surface there. Similarly, isochrons along the valley south of Van Etten might be re-interpreted as a fault that is down to the east. Even if the north-south valleys do not correspond to faults on the Lockport Dolomite, they probably correspond to folded structures that are controlled by faults at the basement. West and southwest of Van Etten the contours bend to the northwest, parallel to the northwest valley out of Van Etten. A small dome and a faulted syncline are also present in the southwest quadrant of the map.

Trenton Limestone

Isochron contours on the Ordovician Trenton Limestone (figure F-12) appear to be almost exactly conformal to those on the Lockport Dolomite. Again conspicuous flexures correspond to the north-south valleys. A relatively steep dip is seen north of Spencer.

Theresa Dolomite

The isochrons for the Cambrian Theresa Dolomite (figure F-13) are similar to those for the Lockport Dolomite and the Trenton Limestone, with the exception that two northwest-trending faults forming a graben are seen southwest of Van Etten. The Theresa Dolomite surface appears to be flexed upward on the southwest side of the fault zone. The Trenton Limestone and Lockport Dolomite exhibit small anticlinal or domal structures overlying this fault zone. The presence of a northwest-trending fault zone on this unit and corresponding northwest-trending structures on the Trenton and Lockport units permit us to speculate on the origin of the Van Etten-Odessa lineament. Although this lineament is located three kilometers to the north of the fault zone on the Theresa unit, it is possible that the lineament formed prior to Allegehenian thrusting as a result of movement along a northwest-trending basement fault. The subsequent thrusting episode may have moved the lineament three kilometers to the north.

Tully - Onondaga Interval

The two-way travel-time interval between the top of the Tully Limestone and the top of the Onondaga Limestone varies so little over the area that it cannot be accurately contoured. The interval is 0.175 $\pm$ 0.005 second in the north and west, increasing to 0.185 $\pm$ 0.005 second in the northeast and southeast. The Tully - Onondaga interval measured 411 meters in the Kesselring well.

Onondaga - Lockport Interval

The two-way isochron interval between the tops of the Onondaga Limestone and Lockport Dolomite (figure F-14) contains the greatest apparent thickness variations seen in the area. These variations are probably due to thrusting and flow within the Salina Group salt units. This interval is 819 meters thick in the Kesselring well. The isochron interval is least north of Van Etten, where it measures 0.310 second. It increases to the south along a gradient striking east-northeast. This gradient appears to terminate along an east-northeast line passing through Van Etten. South of this line, interval times of over 0.400 second are seen. Superimposed upon the general south-southeast thickening of the units are several anomalous features. These include north-south deflections of the contours south of Spencer and within a zone to the west of Van Etten, as well as northwest-trending contours along the northwest valley out of Van Etten. In one possible interpretation, the east-northeast-striking gradients may reflect salt thickness variations controlled by Allegehenian thrusting and folding. The north-south-trending disruptions may reflect tear faults which serve to decouple adjacent salt blocks. The weak northwest trends may represent a second episode of faulting.

Lockport - Trenton Interval

Nearly conformal isochrons preclude contouring the Lockport-Trenton time interval. The interval times are 0.385 ± 0.005 second on the east, 0.390 ± 0.005 second toward the northwest and 0.395 ± 0.005 in the center and southwest corners of the area. This interval is 988 meters thick in the Kesselring well.

Trenton - Theresa Interval

In the north and east, the Trenton-Theresa isochron interval (figure F-15) is nearly uniform at 0.305 ± 0.005 second. West of Van Etten the isochron interval gradually increases, reaching a maximum of 0.350 second at the western edge of the area. Because this interval is so far down in the section, increased interval times on the west may reflect thickening of fill within a basement graben. Alternatively, the change could be due to facies changes in the sandstone-dolomite sequence.

DISCUSSION

An interpretation of scattered seismic reflection profiles in south-central New York State has shown that, whereas moderate structures can exist at and above the level of the Salina Group salt units, most of the geology in this area is characterized by relatively low dip. The profiles show some correlation between mapped surface lineaments and subsurface structures, particularly the Buttermilk Creek - Cayuga Lake lineament and the Watkins Glenn - Taughannock lineament, both of which are seen to be subsurface faults.

The outstanding feature seen in the interpretation of the Van Etten data is the structural dissimilarity of units above and below the Salina Group salt units. The existence of this structural discontinuity verifies that a major decollement formed within the salt sequence during Allegehenian thrusting. The presence of complex structures within the salt units, including thrust blocks bounded by tear faults, is indicated by variations in travel-time within the Onondaga-Lockport interval, which incorporates the Salina Group salt sequence.

Prior to choosing specific waste isolation sites within the salt, it is important to identify individual salt blocks that move as a unit. If such blocks exist, their horizontal boundaries should correspond to the locations of steep gradients on the Onondaga-Lockport interval isochron map (figure F-14), and their centers should correspond to the areas of relatively low gradient.

The intersecting linear valleys in the Van Etten area appear to be associated with subsurface structures of several types. The east-trending linear valley between Van Etten and Spencer is clearly related to folding and thrust faulting in and above the salt units. The northwest and south-trending valleys are underlain by synclines in the horizons above the salt units. Doming occurs at the intersection of these synclines. At stratigraphic levels below the salt units, block faulting on the basement seems to control the locus of the south-trending valleys. The northwest-trending valley out of Van Etten may have resulted from northward displacement of another basement-controlled structure.

REFERENCE

Kreidler, W. L., 1959, Selected deep wells and areas of gas production in eastern and central New York, N. Y. State Museum and Science Service Bull. 373.

FIGURE CAPTIONS

Figure F-1 -- An interpretation based on a blinded seismic section across the Woodhull anticline.

Figure F-2 -- Lineaments and seismic lines in the Ithaca area. Dashed lineaments are weakly expressed in the image. Circles denote positions of faults interpreted from the seismic lines.

Figure F-3 -- An interpreted section based on line A. The dashed line at the top of the figure represents the first arrivals.

Figure F-4 -- An interpreted section based on line D.

Figure F-5 -- An interpreted section based on line E.

Figure F-6 -- Lineaments and seismic lines in the Watkins Glen area. Circles denote positions of faults interpreted from the seismic lines.

Figure F-7 -- An interpreted section based on line F.

Figure F-8 -- Locations of seismic lines and linear valleys in the Van Etten area. Valley walls are indicated by the thin lines.

Figure F-9 -- Two-way travel-time contours (in seconds) to the top of the Tully Limestone. Open circles indicate data points along the seismic lines of figure F-8. Interpreted faults are indicated by heavy lines, fold axes by lighter lines.

Figure F-10 -- Two-way travel-time contours (in seconds) to the top of the Onondaga Limestone.

Figure F-11 -- Two-way travel-time contours (in seconds) to the top of the Lockport Dolomite.

Figure F-12 -- Two-way travel-time contours (in seconds) to the top of the Trenton Limestone.

Figure F-13 -- Two-way travel-time contours (in seconds) to the top of the Theresa Dolomite.

Figure F-14 -- Two-way travel-time contours (in seconds) of the Onondaga - Lockport interval.

Figure F-15 -- Two-way travel-time contours (in seconds) of the Trenton - Theresa interval.

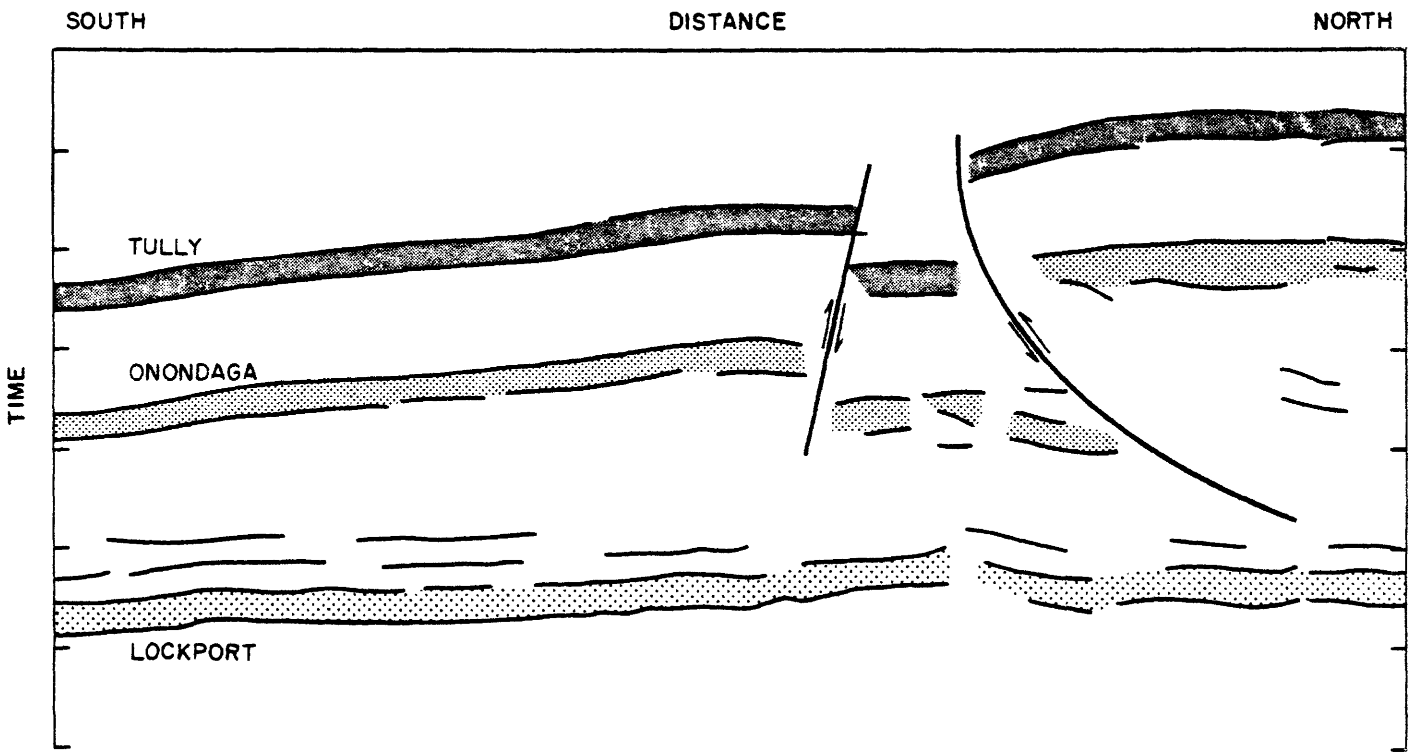


Figure F-1

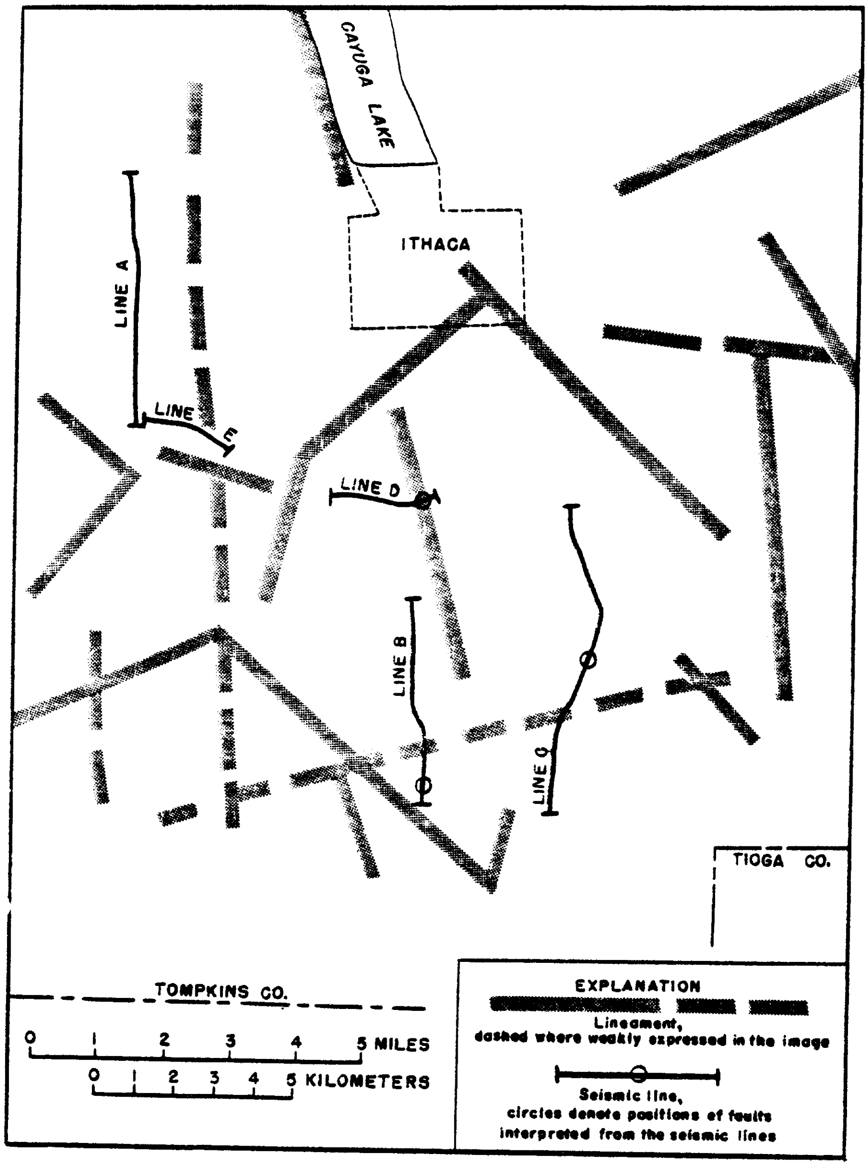

CAYUGA LAKE
ITHACA
LINE A
LINE E
LINE D
LINE B
LINE C
TIOGA CO.
TOMPKINS CO.
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS
EXPLANATION
Lineament,
dashed where weakly expressed in the image
Seismic line,
circles denote positions of faults
interpreted from the seismic lines

Figure F-2

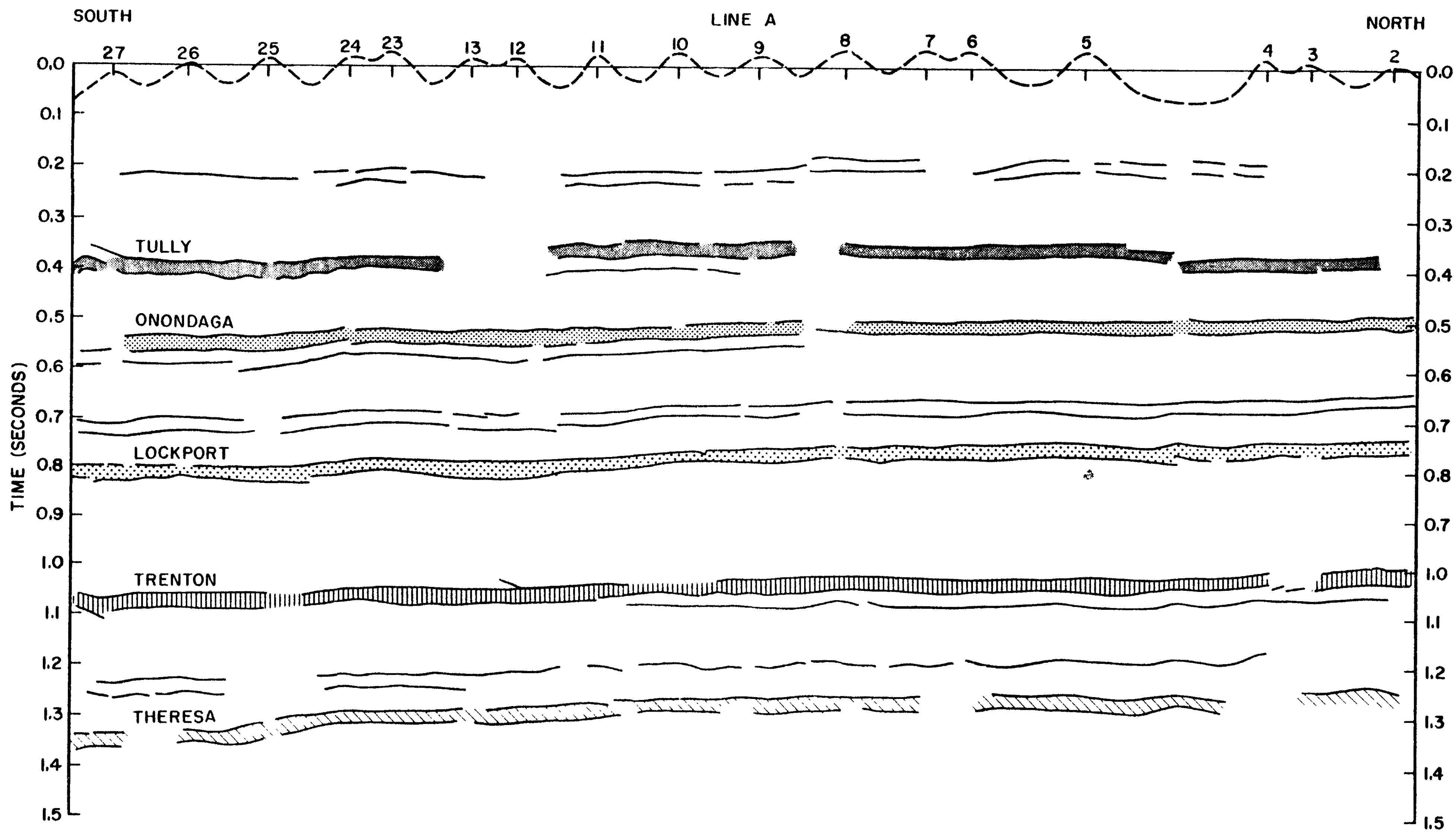
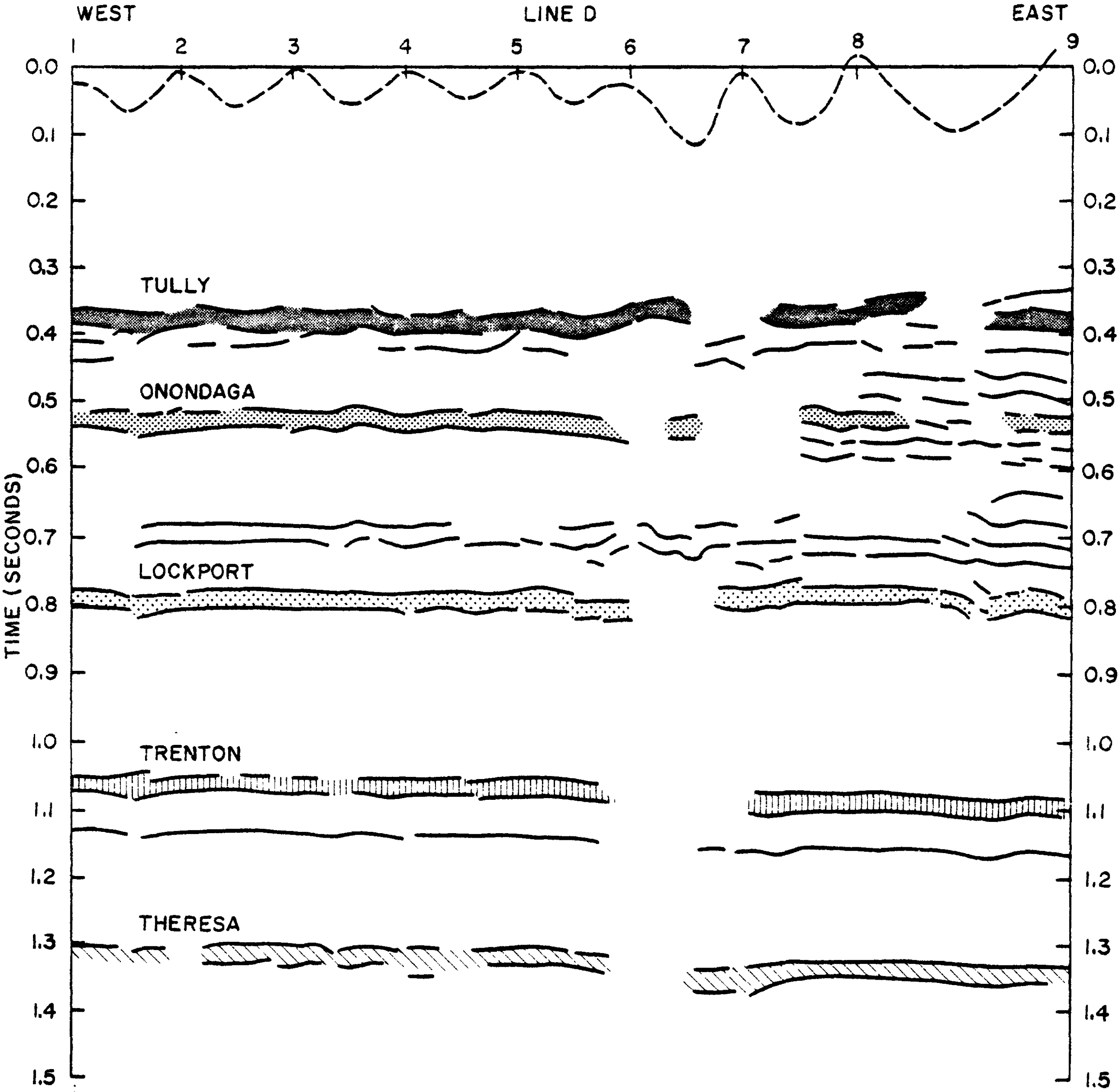

SOUTH
LINE A
NORTH
27
26
25
24
23
13
12
11
10
9
8
7
6
5
4
3
2
TULLY
ONONDAGA
LOCKPORT
TRENTON
THERESA
TIME (SECONDS)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5

Figure F-3



WEST
LINE D
EAST
1
2
3
4
5
6
7
8
9
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
TIME (SECONDS)
TULLY
ONONDAGA
LOCKPORT
TRENTON
THERESA

Figure F-4

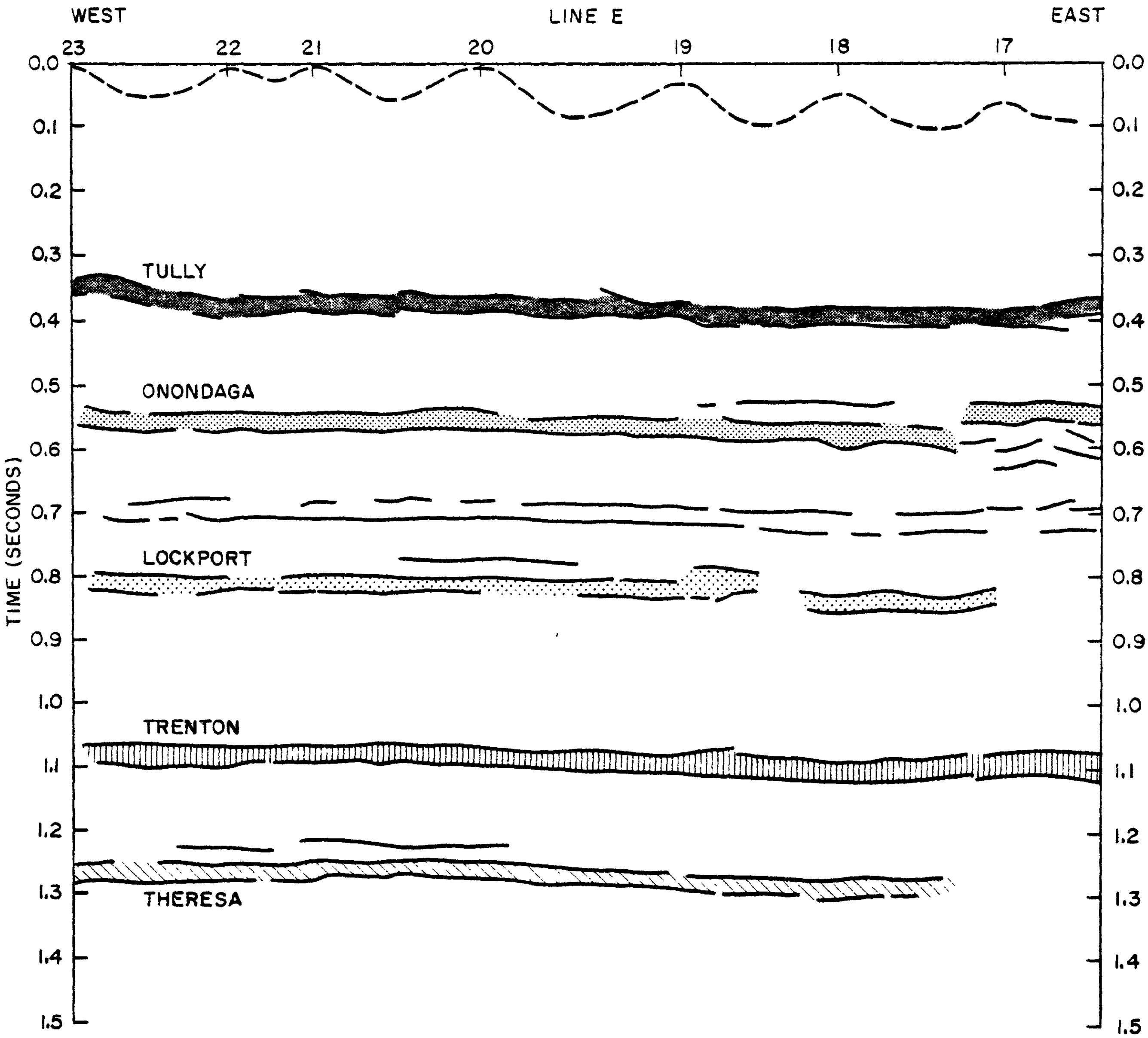

WEST
LINE E
EAST
23
22
21
20
19
18
17
TIME (SECONDS)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
TULLY
ONONDAGA
LOCKPORT
TRENTON
THERESA

Figure F-5

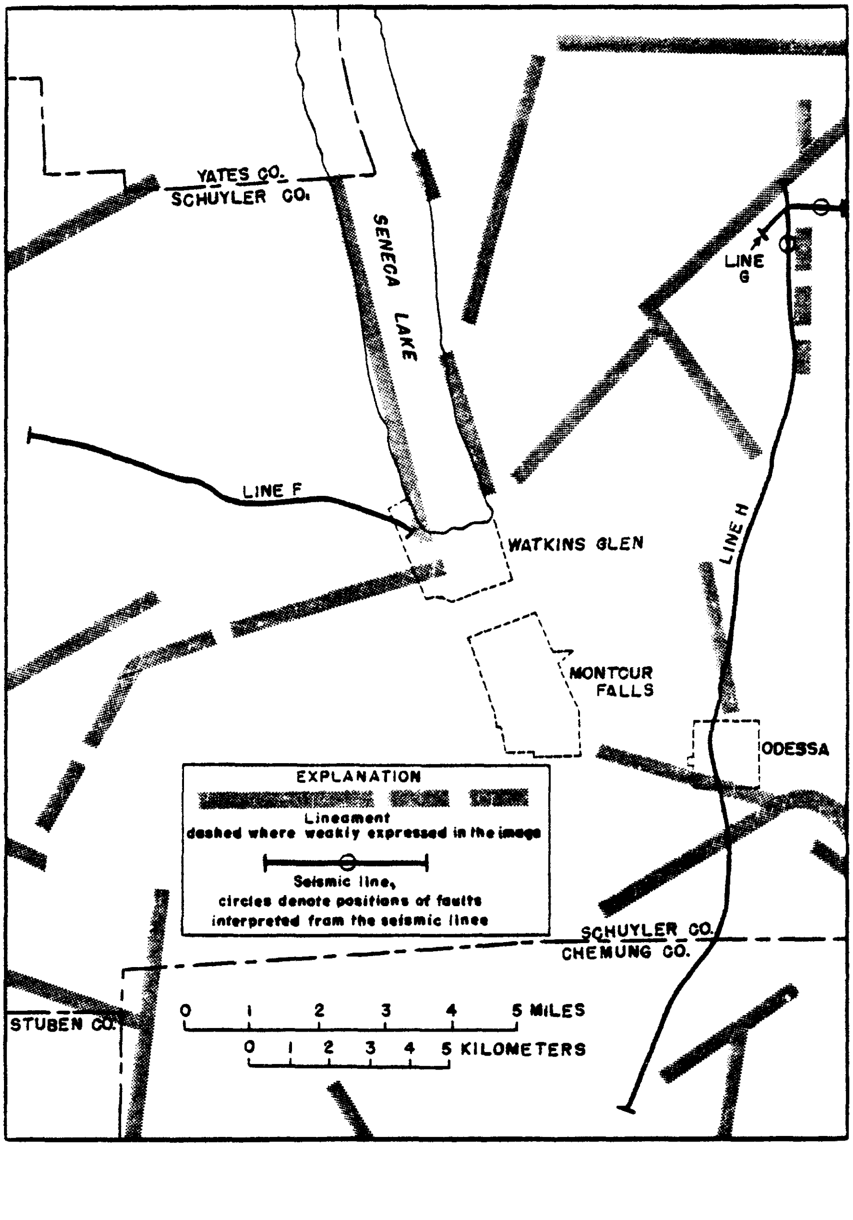

YATES CO.
SCHUYLER CO.
SENEGA LAKE
LINE G
LINE F
WATKINS GLEN
LINE H
MONTOUR FALLS
ODESSA
EXPLANATION
Lineament
dashed where weakly expressed in the image
Seismic line,
circles denote positions of faults
interpreted from the seismic lines
SCHUYLER CO.
CHEMUNG CO.
STUBEN CO.
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS

Figure F-6

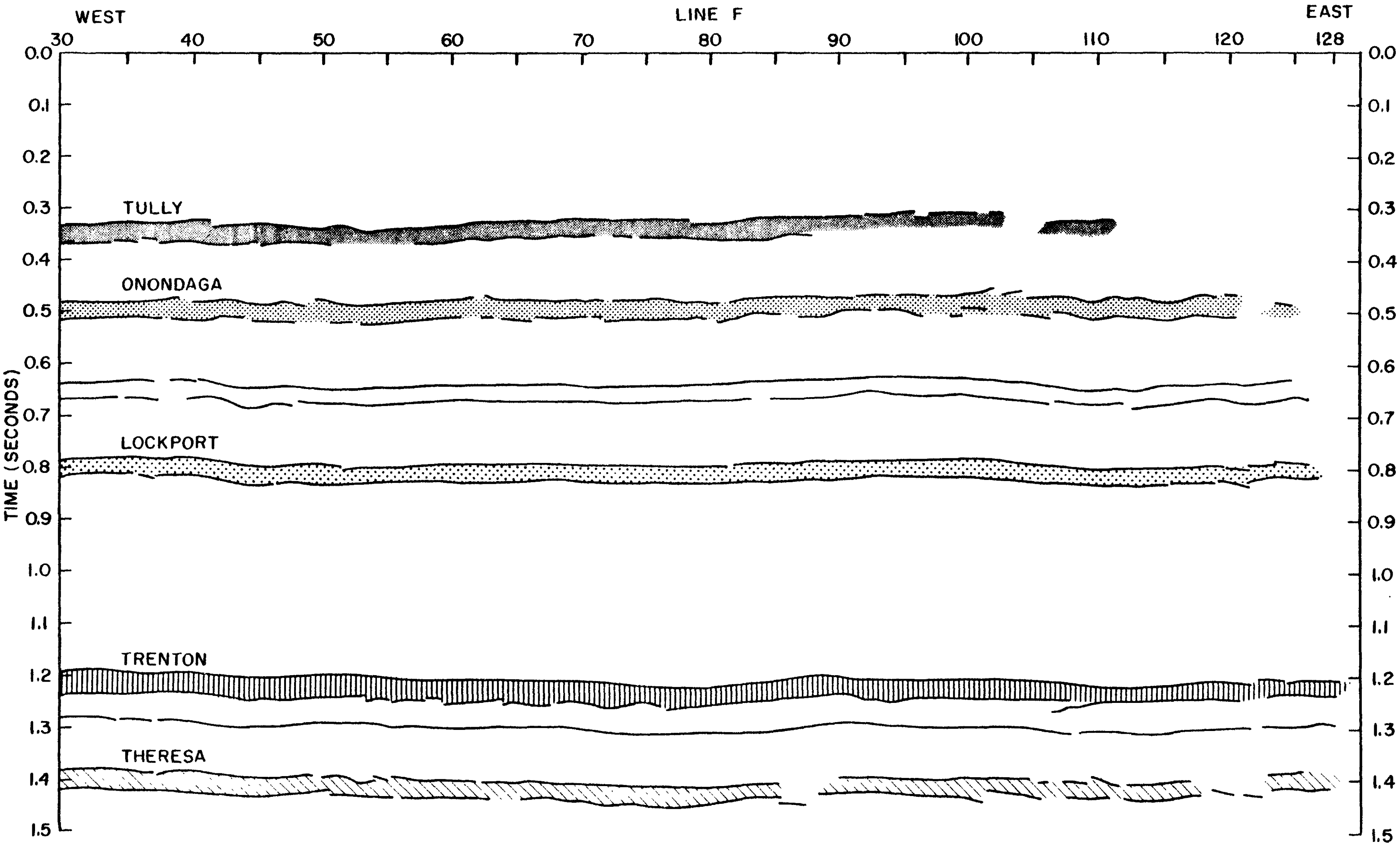
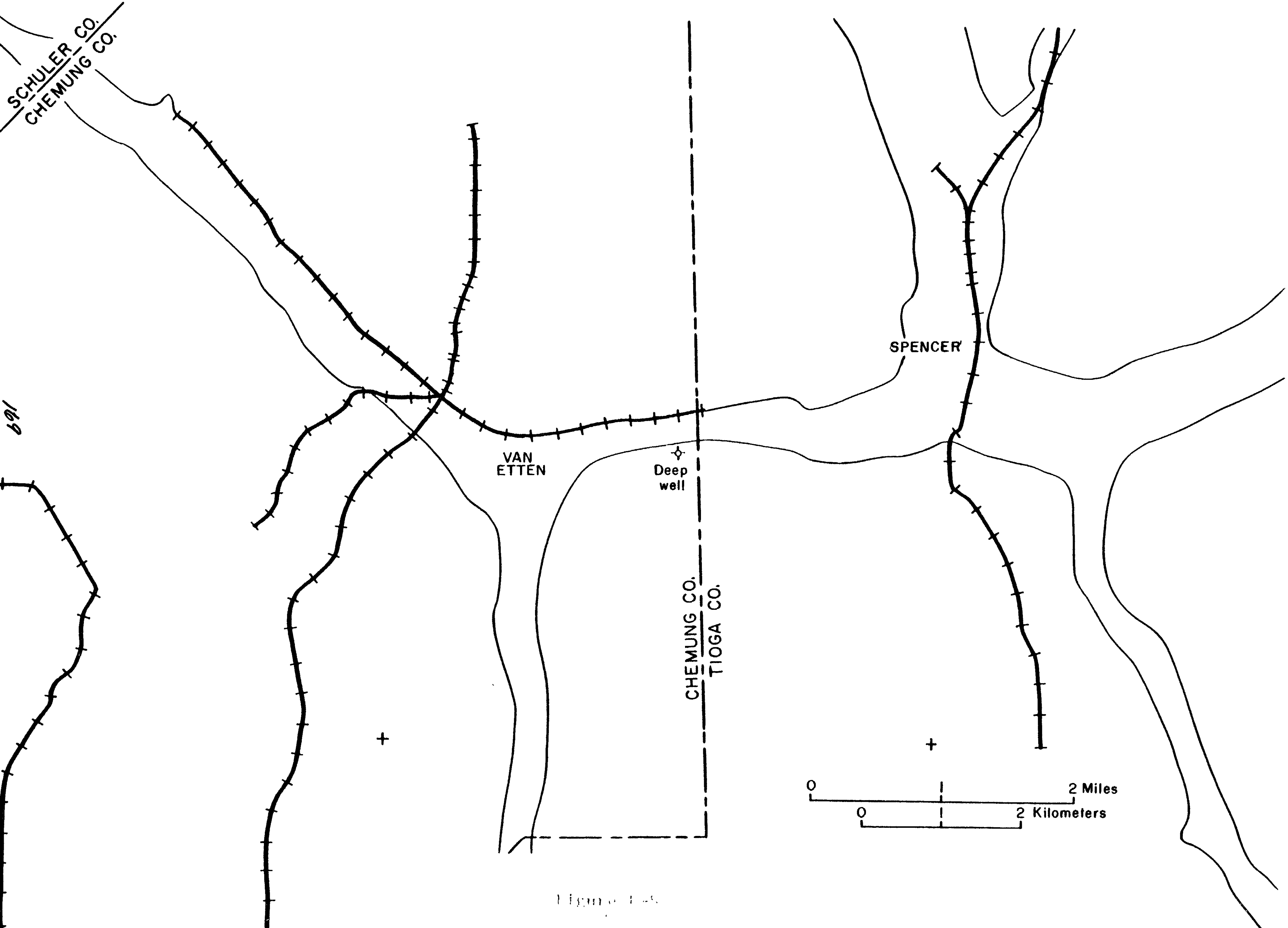

WEST
LINE F
EAST
30
40
50
60
70
80
90
100
110
120
128
TIME (SECONDS)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
TULLY
ONONDAGA
LOCKPORT
TRENTON
THERESA

Figure 1-7


SCHULER CO.
CHEMUNG CO.
VAN ETTEN
Deep well
CHEMUNG CO.
TIOGA CO.
SPENCER
0
2 Miles
0
2 Kilometers

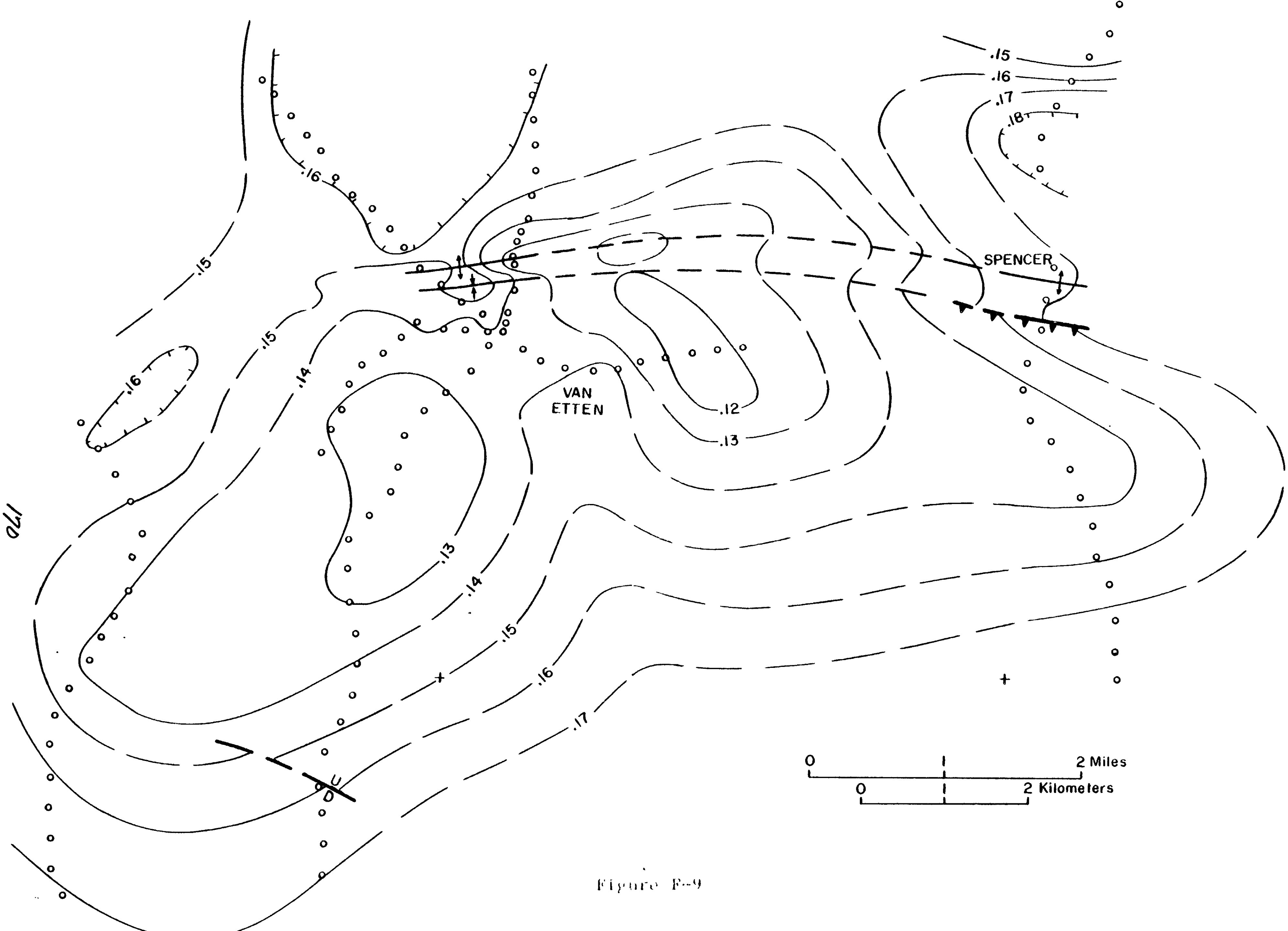

.15
.16
.17
.18
SPENCER
VAN
ETTEN
.12
.13
.14
.15
.16
.17
U
D
0
2 Miles
0
2 Kilometers

Figure F-9

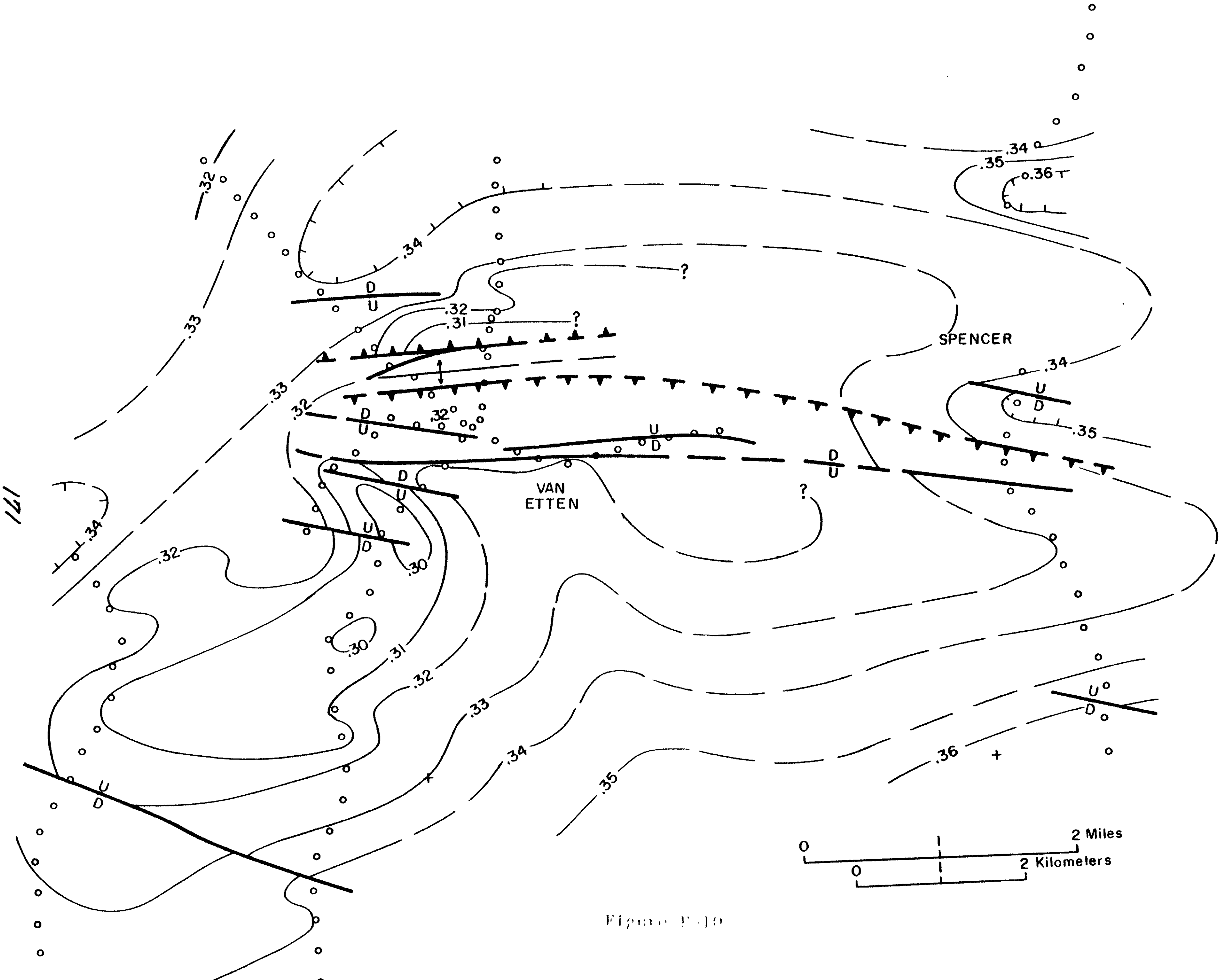
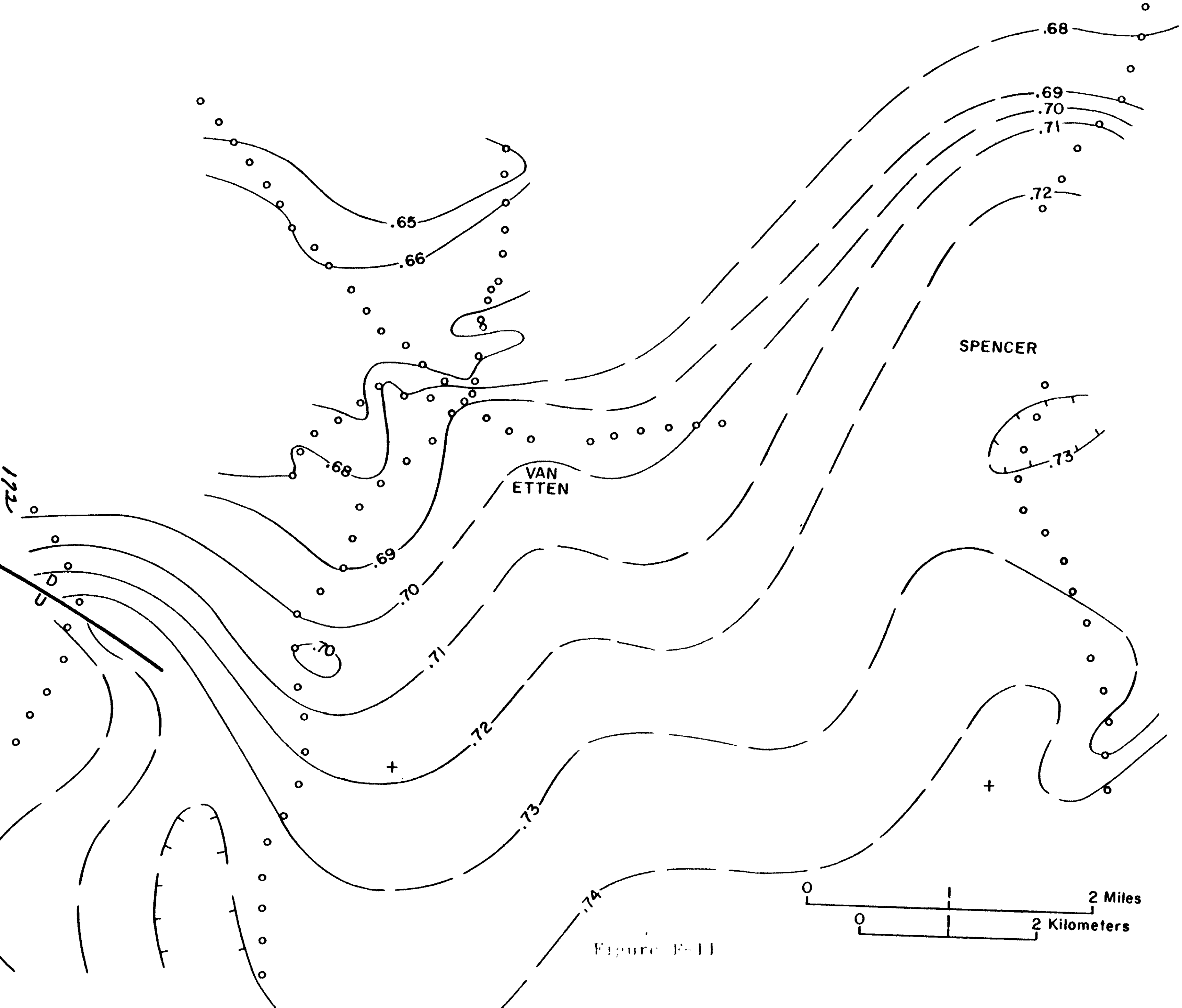

SPENCER
VAN ETTEN
.30
.31
.32
.33
.34
.35
.36
U
D
?
0 2 Miles
0 2 Kilometers

Figure [illegible]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.66
.68
.68
.69
.69
.70
.70
.70
.71
.71
.72
.72
.73
.73
.74
VAN
ETTEN
SPENCER
D
U
0
2 Miles
0
2 Kilometers

Figure F-11

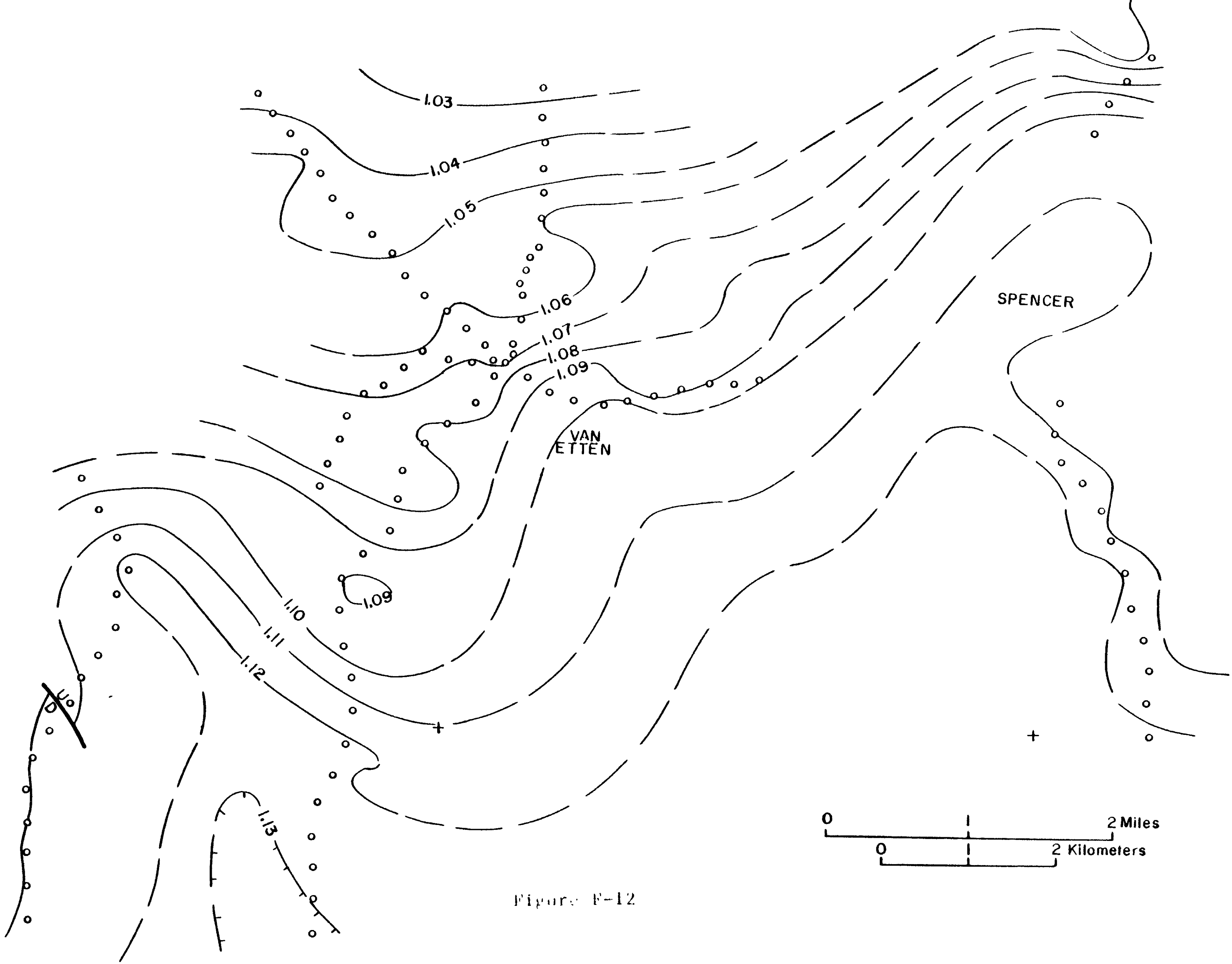
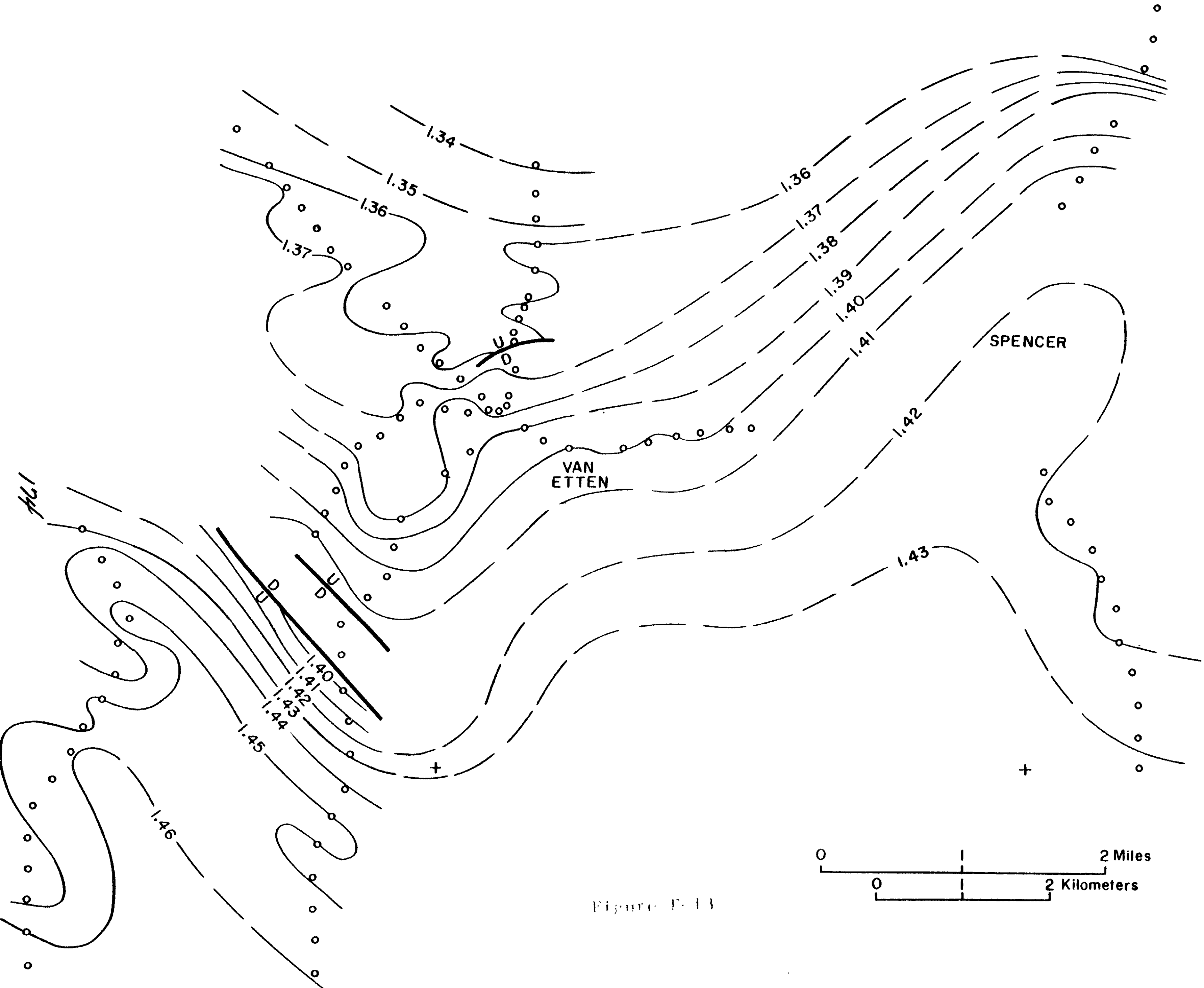

1.03
1.04
1.05
1.06
1.07
1.08
1.09
1.09
1.10
1.11
1.12
1.13
U
D
SPENCER
VAN
ETTEN
0
2 Miles
0
2 Kilometers

Figure F-12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1.35
1.36
1.37
1.38
1.39
1.40
1.41
1.42
1.43
1.44
1.45
1.46
U
D
SPENCER
VAN
ETTEN
0
2 Miles
0
2 Kilometers

Figure F-13

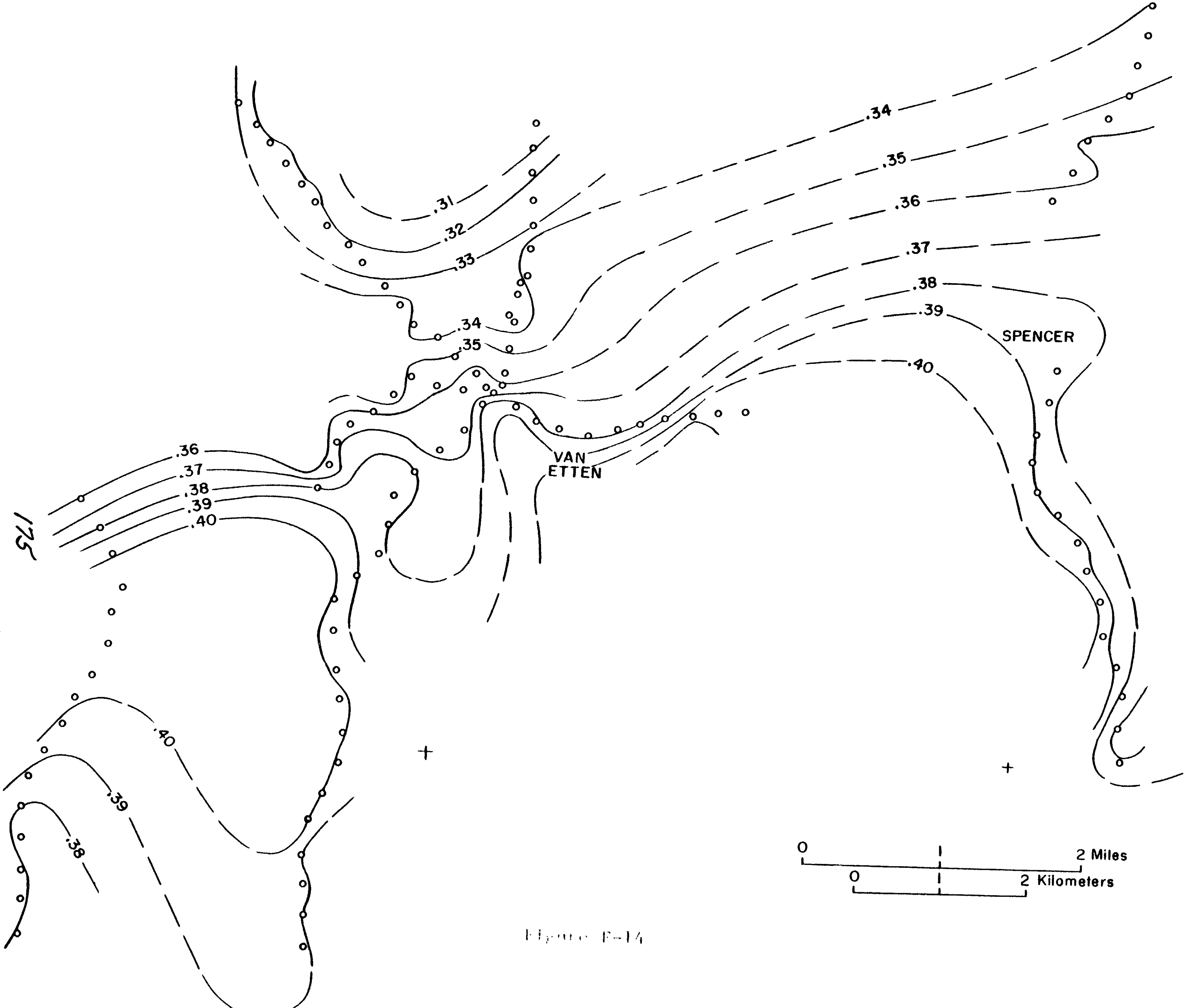
.31
.32
.33
.34
.35
.36
.37
.38
.39
.40
SPENCER
VAN
ETTEN
0
2 Miles
0
2 Kilometers

Figure F-14

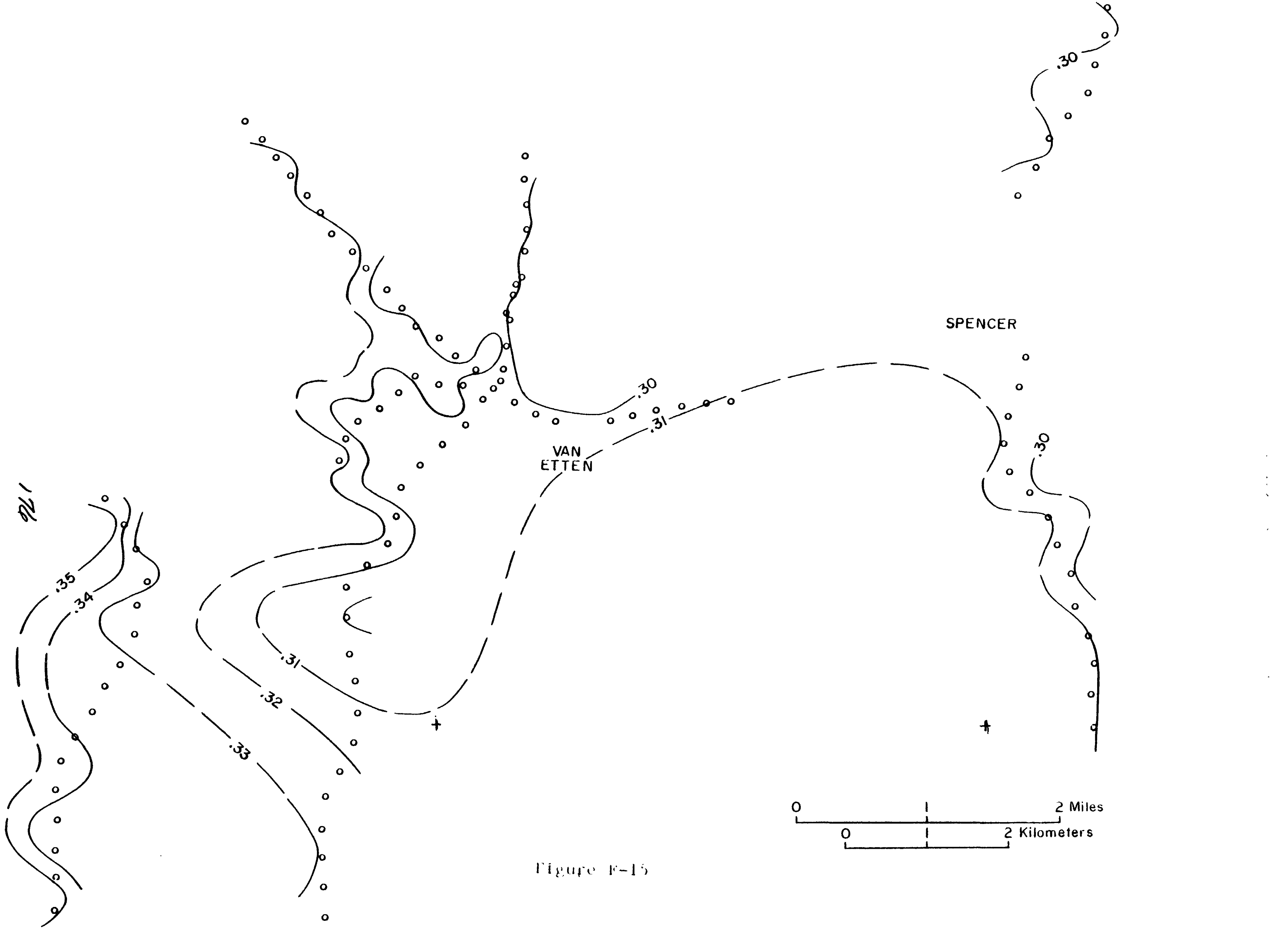
.30
SPENCER
.30
.30
.31
VAN
ETTEN
.31
.32
.33
.34
.35
0
2 Miles
0
2 Kilometers

Figure F-15