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To the Graduate Council:

I am submitting herewith a thesis written by Mark L. Slusarski entitled "Photogeologic fracture traces and lineaments in the Wartburg Basin section of the Cumberland Plateau Physiographic Subprovince, Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geology.

G. Michael Clark, Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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I am submitting herewith a thesis written by Mark L. Slusarski, entitled "Photogeologic Fracture Traces and Lineaments in the Wartburg Basin Section of the Cumberland Plateau Physiographic Subprovince, Tennessee." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geology.

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G. Michael Clark, Major Professor

We have read this thesis and recommend its acceptance:

Don W. Byerly

[illegible]

John B. Rehder

Accepted for the Council:

L. Evans Roth

Vice Chancellor
Graduate Studies and Research

Thesis
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PHOTOGEOLOGIC FRACTURE TRACES AND LINEAMENTS IN THE WARTBURG BASIN SECTION OF THE CUMBERLAND PLATEAU PHYSIOGRAPHIC SUBPROVINCE, TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Mark L. Slusarski

December 1979

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I wish to express my gratitude to Dr. G. Michael Clark for suggesting the subject of this thesis and for his continuous help and guidance during the course of the investigation. I would also like to thank Drs. Dietrich Roeder, Don Byerly, and John Rehder for reading the manuscript and for their suggestions and criticisms during the initial writing of the report.

Financial support for this work was provided by the FMC Corporation. Technical and logistical assistance was provided by Geo, Inc., and in particular Mr. Karl Koch and Mr. Don Miller.

Finally, my special gratitude to my wife Cathi, whose encouragement and understanding were essential to the completion of this manuscript.

ABSTRACT

Photogeologic fracture trace and lineament mapping of the eastern portion of the Wartburg Basin, Tennessee provides important new data on the structural framework of the Cumberland Plateau and makes possible some correlation between remotely sensed linear features and bedrock structure.

Fracture traces and lineaments are generally believed to represent the surface expression of joints, faults, or zones of structural weakness in areas of exposed bedrock. The current investigation attempts to relate photogeologic linear features to bedrock structures in an area where the bedrock is obscured by a deeply-weathered regolith and dense vegetation.

Interpretation of conventional black-and-white panchromatic aerial photographs and other imagery revealed numerous fracture traces and lineaments whose strike frequencies were determined from histograms. Histograms of bedrock fracture orientations were compiled and compared to the photointerpretative data on a regional basis. Gross similarities of strike maxima existed between corresponding photogeologic linear and bedrock fracture histograms. Results were found to be highly dependent upon imagery type and presence or absence of outcrop.

Strike orientations of bedrock fractures and photogeologic linears were directly compared at several sites of known fracture trace or lineament intersection. Comparison revealed a significant parallelism between the strike directions of photogeologic linears and joints that deviated no more than 4° at any of the sites.

Data collected during the investigation indicate that photogeologic fracture traces and lineaments are useful for locating major bedrock structures and areas of increased fracture density. The mapping, although of reconnaissance nature, should provide a basis for future detailed fracture analysis in the Wartburg Basin.

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INTRODUCTION

I. GENERAL DISCUSSION

Fracture traces and lineaments are natural linear features consisting of topographic, vegetational, soil tonal and bedrock alignments which are visible on conventional aerial photographs and other remotely sensed imagery. Blanchet (1957) and Lattman (1958) hypothesized that these natural linear features are the surface expression of faults, joints, or represent planes of weakness thought to extend into the bedrock with depth. They are generally believed to be parallel or subparallel to joint sets in areas where the bedrock is gently dipping.

Fracture analysis can be used to establish a correlation between photogeologic linear features and bedrock structural elements. This is particularly useful for helping to locate deep-seated geologic structures and stratigraphic anomalies over large areas where conventional field methods are impractical due to lack of outcrop, the inaccessibility of the region of study, or time limitations.

II. STATEMENT OF THE PROBLEM

This thesis is a summary of techniques, results, and conclusions formulated during a reconnaissance fracture analysis of a portion of the Wartburg Basin, Cumberland Plateau Physiographic Subprovince, Tennessee (Figure 1). The purpose of the investigation has been several fold:

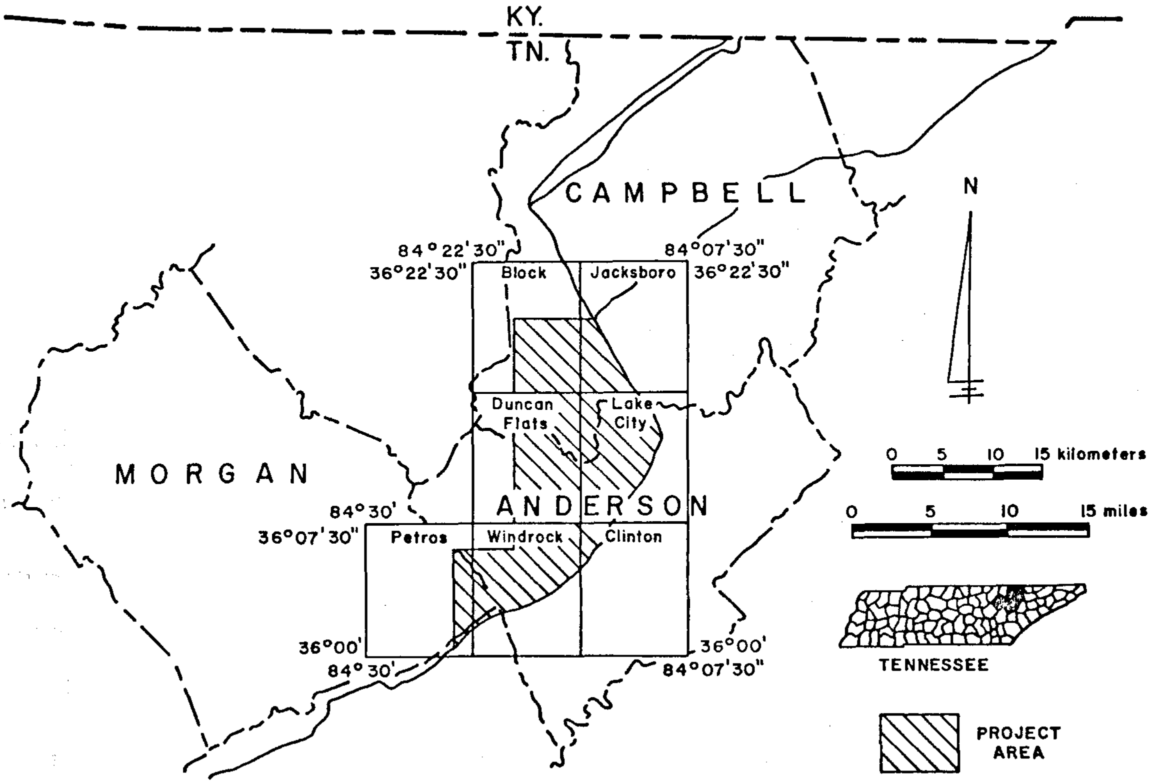

Figure 1. Index map of Anderson, Campbell, and Morgan Counties, Tennessee showing location and extent of project area. Hachured area is shown in Figure 2, page 8.

first, to describe the fracture geometry of the research area in terms of photogeologic linears; secondly, to establish a correlation (if any) between photogeologic linear features and bedrock structural elements; and finally, to compile a photogeologic fracture pattern map.

The research involved two major procedural phases:

1. an interpretative phase in which airborne and orbital imagery was monoscopically and stereoscopically examined and interpreted for apparent fracture traces and lineaments;
2. a phase involving the acquisition of possible correlative field data.

Photogeologic linears were mapped prior to the acquisition of field data to prevent a knowledge of bedrock fracture orientations from introducing a bias. Statistical compilation and comparison of data acquired from both phases of investigation constituted an integral part of the study.

Several factors influenced the selection of the specific location for the testing of the hypothesis:

1. The rocks are relatively undeformed and free of significant structural complexities.
2. The existence of a deeply-weathered regolith supporting a dense vegetative canopy precludes simplified photogeologic fracture trace and lineament mapping.
3. Strip-mines in a region of scarce, natural bedrock exposures would provide access to critical areas where bedrock fracture orientations could be observed.

4. The region is covered by easily obtained imagery at varying scales.

5. A detailed fracture pattern analysis could prove advantageous to a region of increasing economic importance, specifically in terms of petroleum exploration.

III. PREVIOUS INVESTIGATIONS

As far as the writer could determine, a detailed photogeologic fracture analysis of the study area has not been previously undertaken or is not available in the public domain.

Repetitious linear patterns in relief and hydrography represented by lines that are essentially rectilinear, were described by Hobbs (1911) and designated "lineaments—significant lines in the earth's surface." Hobbs considered "the control of direction, not the details of sculpture" as the most significant characteristic of lineaments and recognized the importance of jointing as a mechanism of expression in areas where there are no discernable faults.

The connotation of the term "lineament" which is generally accepted at present was proposed by Kaiser (1950) who stated:

> A lineament is a straight linear feature that is at least many hundreds of feet and commonly many miles long. Lineaments are well shown on aerial photographs and may consist of (1) linear topographic features, either trenches or ridges; (2) linear vegetation patterns; or (3) linear patterns of soil color or texture.

Blanchet (1957) determined that not only is the earth's crust systematically fractured, but the fracture patterns are recognizable on aerial photographs and could be used to interpret the presence of structures of deep-seated origin. Lattman and Nickelsen (1958) proposed that fracture traces and lineaments represented joints or zones of joint concentration. They determined that all photogeologic linears were not conclusively related to bedrock joints or joint directions and could be projected into areas obscured by unconsolidated waste rock or vegetation only when supported by correlative field data.

IV. RESEARCH APPLICATIONS AND ECONOMIC BENEFITS

Research involving aerially mapped fracture patterns is specifically intended to achieve an insight on the nature of subsurface structures over large areas with minimum expenditures of time and money.

A knowledge of fracture orientations is of increasing importance for a variety of industrial and geological applications. Such a study could be of particular interest in evaluating the suitability of potential nuclear and conventional power generation sites. Geologically, fracture traces and lineaments are considered to represent tectonic or regional fractures that may serve as areas of increased hydraulic permeability, zones of mineral concentration and localization, or conduits for natural gas and oil migration.

In terms of specific economic value, fracture analysis has proven beneficial in determining fracture orientations in oil-gas reservoirs. Natural fracture systems are common structural components of petroleum reservoirs. Heck (1955) believed that surface joints existed as closed planes which might be forced open by well-bore fracturing procedures. Much work has been done by the U.S. Bureau of Mines regarding this hypothesis. Komar, Overbey, Rough and Lambert (1971) determined that a relationship between hydraulically induced vertical well-bore fractures and surface joints and other lineations existed. Induced well-bore fractures tended to be oriented parallel or subparallel to surface structural trends and possessed higher reservoirs permeabilities. If fractures with known orientations could be induced in inefficiently producing petroleum reservoirs, sweep efficiencies of injected fluids could be optimized. Aerially mapped linears have demonstrated a significance not only in terms of secondary-recovery projects and reservoir engineering but as a tool for deducing the structural nature of the bedrock in areas underlain by gently dipping strata.

CHAPTER II

THE RESEARCH AREA

I. GENERAL GEOLOGIC SETTING

The area of study is the eastern portion of the Wartburg Basin of the Cumberland Plateau (Figure 2). The Cumberland Plateau section of the Appalachian Plateaus Physiographic Province trends northeast-southwest across Tennessee. To the east and west its margins are delineated by outward facing escarpments. The dominant structural component of the plateau is the gentle eastward dip of Upper Palezoic sediments off the flank of the Cincinnati Arch (Wilson et al., 1958).

II. LOCATION AND EXTENT OF AREA

The research area described in this thesis is located in Anderson, Campbell, and Morgan Counties and lies within the Jacksboro, Lake City, Clinton, Block, Duncan Flats, Windrock, and Petros Quadrangles. It is a section of the Wartburg Basin bounded on the west from a point on the Eastern Cumberland Escarpment by longitude 84°24', north to latitude 36°06', east to longitude 84°19'30", north to latitude 36°19', east to the Jacksboro fault (see Plate I). To the northeast and southeast the area is respectively bounded by the Jacksboro fault and Walden Ridge (North). The total area of the region under discussion is approximately 129 square miles (334 sq. km.) or 24 percent of the Wartburg Basin.

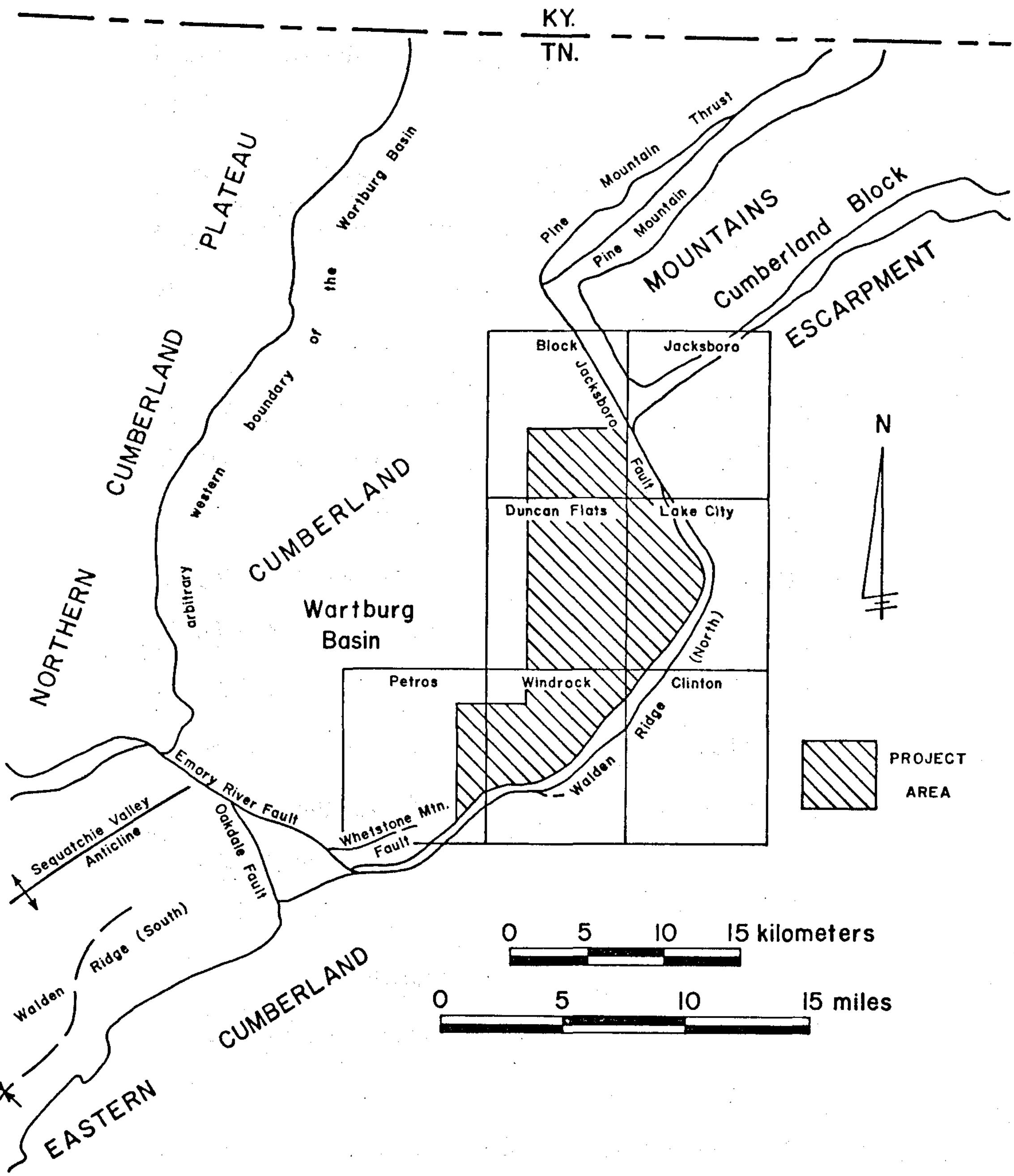

Figure 2. Location and extent of project area with respect to the regional geologic framework. (After Wilson et al., 1956)

III. RELIEF AND DRAINAGE

The northeastern boundary of the Wartburg Basin is delineated by Cove Creek valley (Jacksboro fault) and Walden Ridge (North). To the northeast and southeast Walden Ridge (North) forms a prominent escarpment underlain by resistant, steeply inclined, Lower Pennsylvanian sandstones and conglomerates.

The Wartburg Basin of the Cumberland Plateau is characterized by strong local relief. Elevations within the project area range from 840 feet (256m) above sea level, to a maximum elevation of 3534 feet (1077.2m) on the summit of Cross Mountain located in the Lake City quadrangle. Slopes average 46.6 percent (25°) with a variance around this average of 38.4 to 72.7 percent (21° to 36°) (Appalachian Resources Project, 1976). Differential erosion of thick sandstones underlying relatively horizontal shales and siltstones have resulted in the formation of prominent topographic benches at varying elevations on the mountain slopes (McCallum, 1958).

The culmination of relief along the crests of Cross, Red Oak, and Windrock mountains is coincidental with the Tennessee Valley Divide (see Plate I). The drainage network east of the divide consists of steep-sided, bifurcating ridges and a system of deeply entrenched, stream valleys. West of the divide the drainage pattern is markedly dendritic and exhibits a high degree of bedrock structural influence as indicated by numerous, systematic, straight-stream segments at acute angles to each other. The region is typically mountainous and in a stage of mature dissection.

IV. STRUCTURE

The Wartburg Basin is a broad, well defined structural subprovince characterized by horizontally bedded rocks that are essentially undisturbed (Wilson and Stearns, 1958). Structure contour maps using several regionally persistant stratigraphic units as datum indicate a gradual rise to the west-northwest averaging 25 feet per mile. Regional strike is to the northeast.

The basin is bounded on the northeast by the Jacksboro-Pine Mountain fault system, on the southeast by Walden Ridge (North), and on the southwest by the Cumberland Plateau overthrust, of which the Emory River fault is a major component. To the west-northwest the Wartburg Basin is arbitrarily limited and merges with the Northern Cumberland Plateau (Wilson et al., 1956).

V. STRATIGRAPHY

With the possible exception of formations that locally thin and pinch out, the entire stratigraphic sequence of Pennsylvanian rocks in Tennessee is preserved in the Cumberland Mountains of the Wartburg Basin (Figure 3). The Wartburg Basin is underlain by Pennsylvanian age rocks consisting primarily of sandstones, siltstones, and shales. Conglomerates, limestones, and coals of local extent are also present (Luther, 1959).

Revisions in nomenclature and the placement of formation boundaries in the upper 1800 feet of the stratigraphic sequence were proposed by Barlow (1969). Barlow divides this section into upper and lower

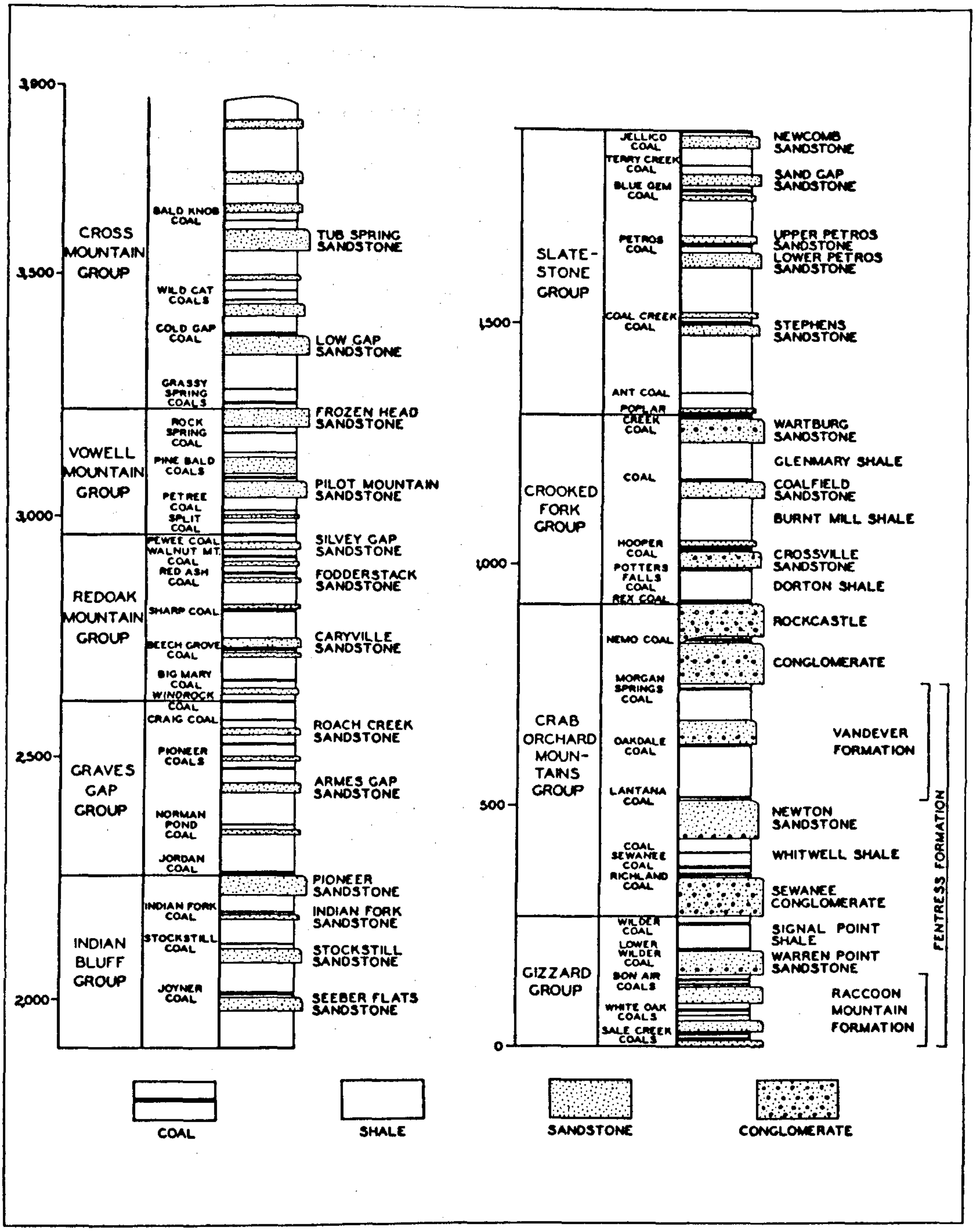

Figure 3. Generalized stratigraphic sequence of Pennsylvanian rocks in the Wartburg Basin, Tennessee. (After Luther, 1959)

divisions on the basis of gross lithology and the presence or absence of economically important coal measures.

The Cross Mountain, Vowell Mountain, Red Oak Mountain, and Graves Gap groups above the upper Pioneer Coal are collectively referred to as the Cross Mountain Group and constitute the upper division. The predominant rock types are sandstones and siltstones with lesser amounts of shale. The upper division is characterized by numerous coal seams of sufficient thickness and grade to be economically valuable.

The base of the Cross Mountain Group and the top of the Pioneer Sandstone respectively constitute the upper and lower boundaries of the lower division (Graves Gap Group). Siltstones interbedded with occasional sandstones predominate. Several coals of little economic importance are also present.

CHAPTER III

PHOTOINTERPRETATIVE PHASE OF RESEARCH

I. TERMINOLOGY AND DEFINITIONS

The nomenclature concerning photogeologic linear features has continually evolved and has been redefined since the early descriptions of Hobbs (1911). In this report usage of the terms "fracture trace" and "lineament" is restricted to the definitions proposed by Lattman (1958),

> A photogeologic fracture trace is a natural linear feature consisting of topographic (including straight stream segments), vegetation, or soil tonal alignments, visible primarily on aerial photographs, and expressed continuously for less than one mile. Only natural linear features not obviously related to outcrop pattern of tilted beds, lineation and foliation, and stratigraphic contacts are classified as fracture traces. Included in this term are joints mapped on aerial photographs where bare rock is observed.
>
> A photogeologic lineament is a natural linear feature consisting of topographic (including straight stream segments), vegetation, or soil tonal alignments, visible primarily on aerial photographs or mosaics, and expressed continuously for at least one mile, but which may be expressed continuously or discontinuously for many miles. The restrictions placed on the term "fracture trace" as regards origin apply equally to the term "lineament."

The length of the linear feature is the parameter that distinguishes fracture traces from lineaments. It is important to bear in mind that "fracture trace" rather than "fracture" is the preferred terminology because in regions where dense vegetative canopies or thick soil mantles exist, only the indirect surficial expression of the fault or joint is evident and not the structure itself.

Fracture traces and lineaments can be classified on the basis of genesis and relation to structure. Fracture traces (micro-fractures) have been related to bedrock joints (Lattman and Nickelsen, 1958) and attributed to local jointing or small scale local faulting. Kaiser (1950) and Blanchet (1957) considered lineaments (macro-fractures) to represent the surficial expression of major shatter zones or faults in the basement.

II. AERIAL PHOTOGRAPHIC AND OTHER REMOTE SENSING IMAGERY

Recent coverage of the project area was provided by black and white panchromatic, hyper-altitude infrared, and LANDSAT multispectral imagery of varying scales (Table I). Of particular importance is the consideration of the date of the imagery as surficial expression of linear features is modified by seasonal vegetational changes. Scale of imagery determines the minimum sized linear feature that can be discerned.

CAS and ASCS panchromatic, "minus-blue" aerial photographs were used exclusively for the purpose of mapping in detail the photogeologic fracture traces and lineaments. The large nominal scales of these photographs (1' = 1500", 1' = 1667", 1' = 3000") permitted the identification of linear features as little as 400 feet (121.8m) in length. Small scale hyper-altitude and LANDSAT imagery (RF 1:120000, RF 1:500000) was compared to conventional black and white photographs to determine which linear features (if any) could be discerned from higher altitudes and if imagery of contrasting spectral sensitivities would enhance or obscure their surficial definition.

TABLE I

PHOTOGRAPHIC AND NONPHOTOGRAPHIC IMAGERY UTILIZED IN THE INTERPRETATIVE PHASE OF FRACTURE TRACE AND LINEAMENT ANALYSIS IN THE WARTBURG BASIN

SOURCE	IMAGERY TYPE	FORMAT	IMAGE SIZE	DATE OF IMAGERY	NOMINAL SCALE	AREA OF NEGATIVE COVERAGE
CONTINENTAL AERIAL SURVEYS, INC. (CAS) ALCOA, TN	BLACK & WHITE PANCHROMATIC	CONTACT PRINT	9 IN. X 9 IN. 22.9 CM. X 22.9 CM.	NOV., 1976	RF 1 : 18000 1" = 1500'	6.6 SQ. MI. 17.1 SQ KM.
CONTINENTAL AERIAL SURVEYS, INC. (CAS) ALCOA, TN	BLACK & WHITE PANCHROMATIC	CONTACT PRINT	9 IN. X 9 IN. 22.9 CM. X 22.9 CM.	NOV., 1974	RF 1 : 36000 1" = 3000'	26.2 SQ. MI. 67.9 SQ. KM.
AGRICULTURAL STABILIZATION AND CONSERVATION SERVICE (ASCS) AERIAL PHOTOGRAPHY FIELD OFFICE SALT LAKE CITY, UT	BLACK & WHITE PANCHROMATIC	CONTACT PRINT	9 IN. X 9 IN. 22.9 CM. X 22.9 CM.	OCT., 1973	RF 1 : 20000 1" = 1667'	8.1 SQ. MI. 21.0 SQ. KM.
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA) EROS DATA CENTER SIOUX FALLS, SD	HYPER-ALTITUDE COLOR IR	FILM BASE POSITIVE TRANSPARENCY	9 IN. X 9 IN. 22.9 CM. X 22.9 CM.	APRIL 1972	RF 1 : 120,000	$(17.1\ MI.)^2$ $(44.2\ KM.)^2$
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA) EROS DATA CENTER SIOUX FALLS, SD	LANDSAT MULTISPECTRAL SCANNER MSS BAND 5 (RED)	CONTACT PRINT	14.6 IN. X 14.6 IN. 37 CM. X 37 CM.	JULY 1973	RF 1 : 500,000	$(115.2\ MI.)^2$ $(298.4\ KM.)^2$
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA) EROS DATA CENTER SIOUX FALLS, SD	LANDSAT MULTISPECTRAL SCANNER MSS BAND [4 (GREEN), 5 (RED), 7 (PHOTO. IR)] COLOR COMPOSITE	CONTACT PRINT	14.6 IN. X 14.6 IN. 37 CM. X 37 CM.	JULY 1973	RF 1 : 500,000	$(115.2\ MI.)^2$ $(298.4\ KM.)^2$

III. PROCEDURE

The imagery was inspected monoscopically and stereoscopically for photogeologic fracture traces and lineaments. Proper orientation and spacing of stereopairs permitted accurate stereoscopic examination, a technique which enhances topographic relief and enables subtle differences in elevation to become apparent. This is critical in the identification and differentiation of topographic-erosional and vegetational alignments. The fracture patterns were annotated on stable, transparent acetate overlays and transferred to 7-½ minute topographic quadrangle base maps. Comparison of the photograph location of linears with the plotted location on the topographic map insured accurate transfer of data and eliminated fracture trace and lineament mislocation due to distortion in the photograph.

Factors influencing interpretation included nominal scale of imagery, date of photography, photographic contrast, and general photographic quality or the presence of imperfections. Careful inspection of the imagery reduced the possibility of mapping cultural, nongeologic linear features such as trails, old roads, and abandoned tram and fence lines.

Classification and analysis of each linear feature was facilitated through the development of a chart tabulating individual characteristics (Figure 4). The data pertains to the composition, manner of expression, continuity, and dimensional parameters of the fracture trace or lineament. Composition refers to whether the photogeologic linear was expressed as a single interpretative element or a combination of elements.

PHOTOINTERPRETIVE FRACTURE TRACE AND LINEAMENT DATA																
IMAGE NO.	EMULSION TYPE			FRACTURE TRACE NO.	COMPOSITION		PHOTOGEOLOGIC LINEAR EXPRESSION ELEMENTS					CONTINUITY		FRACTURE TRACE PARAMETERS		
									TOPOGRAPHIC — EROSIONAL ALIGNMENTS							
	NORMAL B&W PANCHROMATIC	B&W I.R.	COLOR I.R.		SINGLE PHOTOINTERPRETIVE ELEMENT	MULTIPLE PHOTOINTERPRETIVE ELEMENTS	SOIL TONAL ALIGNMENT	VEGETATIONAL ALIGNMENT	STREAM SEGMENT ALIGNMENTS	VALLEY OR RIDGE AXES ALIGNMENTS	REMARKS	CONTINUOUS LINEAR ELEMENT(S)	SUBCONTINUOUS LINEAR ELEMENT(S)	MAPPABLE LENGTH	MAPPABLE WIDTH	ORIENTATION

Figure 4. Organization and format of chart used to tabulate individual photogeologic linear characteristics.

Fracture traces and lineaments appear as thin, relatively straight features that are expressed as vegetational, soil tonal, or topographic-erosional alignments, including straight stream segments and ridge or valley axes. Photogeologic linears may be expressed continuously or intermittently. An interpretative determination must be made as to whether individual segments are genetically related to a single photogeologic feature.

Accurate assessment of mappable width was for the most part limited to the largest scale imagery and dependent upon seasonal vegetative conditions existent at the time of photographic exposure. Early autumn photographs of woodland canopies concealed soil tonal contrasts. As a result, measurements of width were generally restricted to vegetational alignments expressed as higher stands of timber a single tree crown wide. Light and dark soil tonal contrasts 100 to 200 feet in width, indicative of zones of multiple fractures, were evident in late autumn photographs after the vegetative cannopy had diminished and the regolith was exposed. Mappable width was indeterminate on the less detailed, small scale imagery taken at higher elevations as tonal contrasts due to soil moisture or foliage were indistinguishable from one another.

After transferrence to 7-½ minute topographic quadrangle maps the azimuth of each photogeologic linear was recorded and its length measured.

It should be emphasized that mapped fracture traces and lineaments are indicative of fracture trends and do not necessarily reflect individual structures. In many instances a zone of fault or joint concentration is being observed. Examples of photogeologic linear features visible on imagery of the research area and the corresponding fracture orientations on each image are present in Figures 5, 6, 7, 8, 9, and 10.

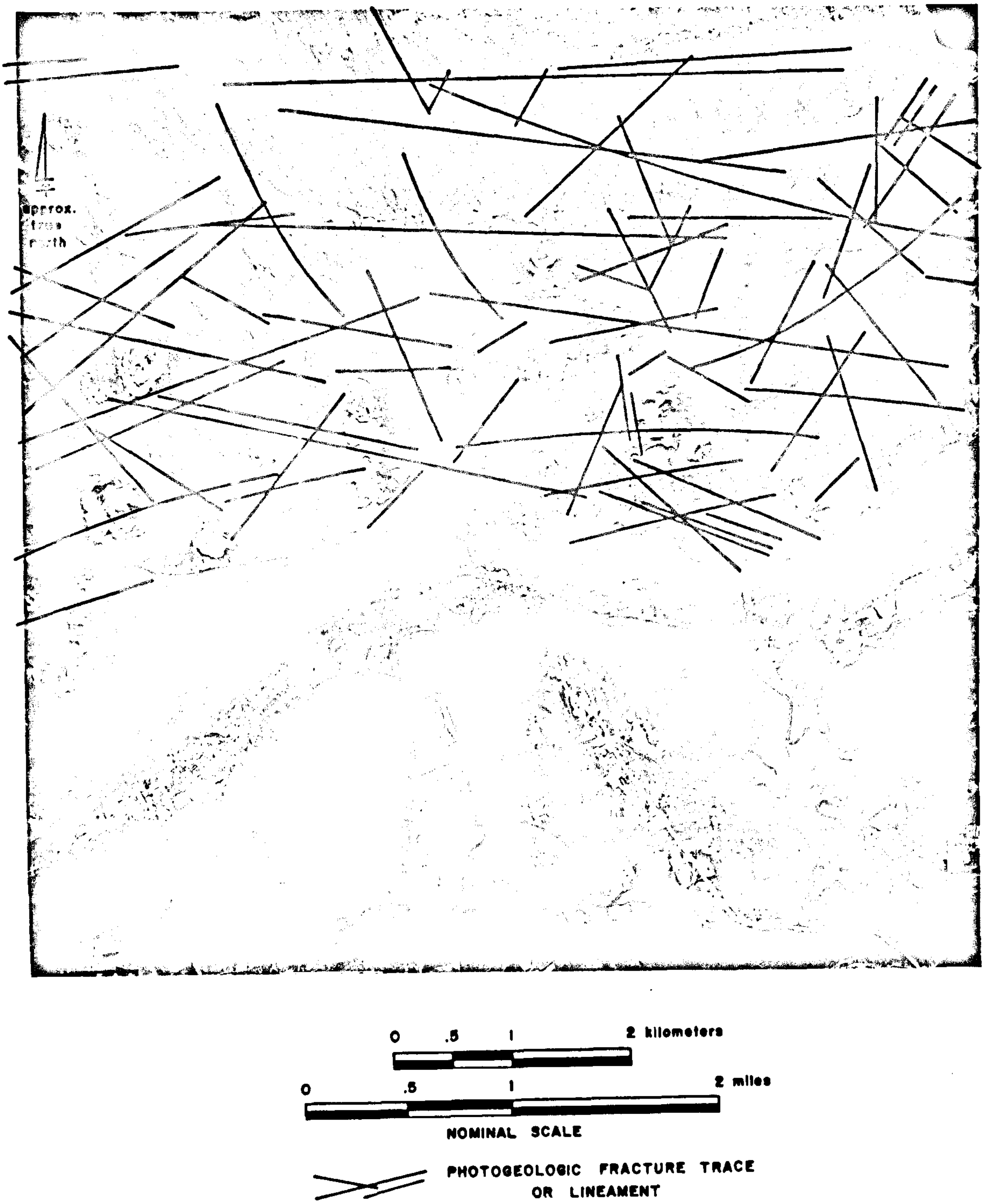

Figure 5. Aerial photograph of Oliver Springs, Walden Ridge, and adjacent Wartburg Basin of the Cumberland Plateau. Photogeologic linear trends visible within the region are represented on transparent overlay.

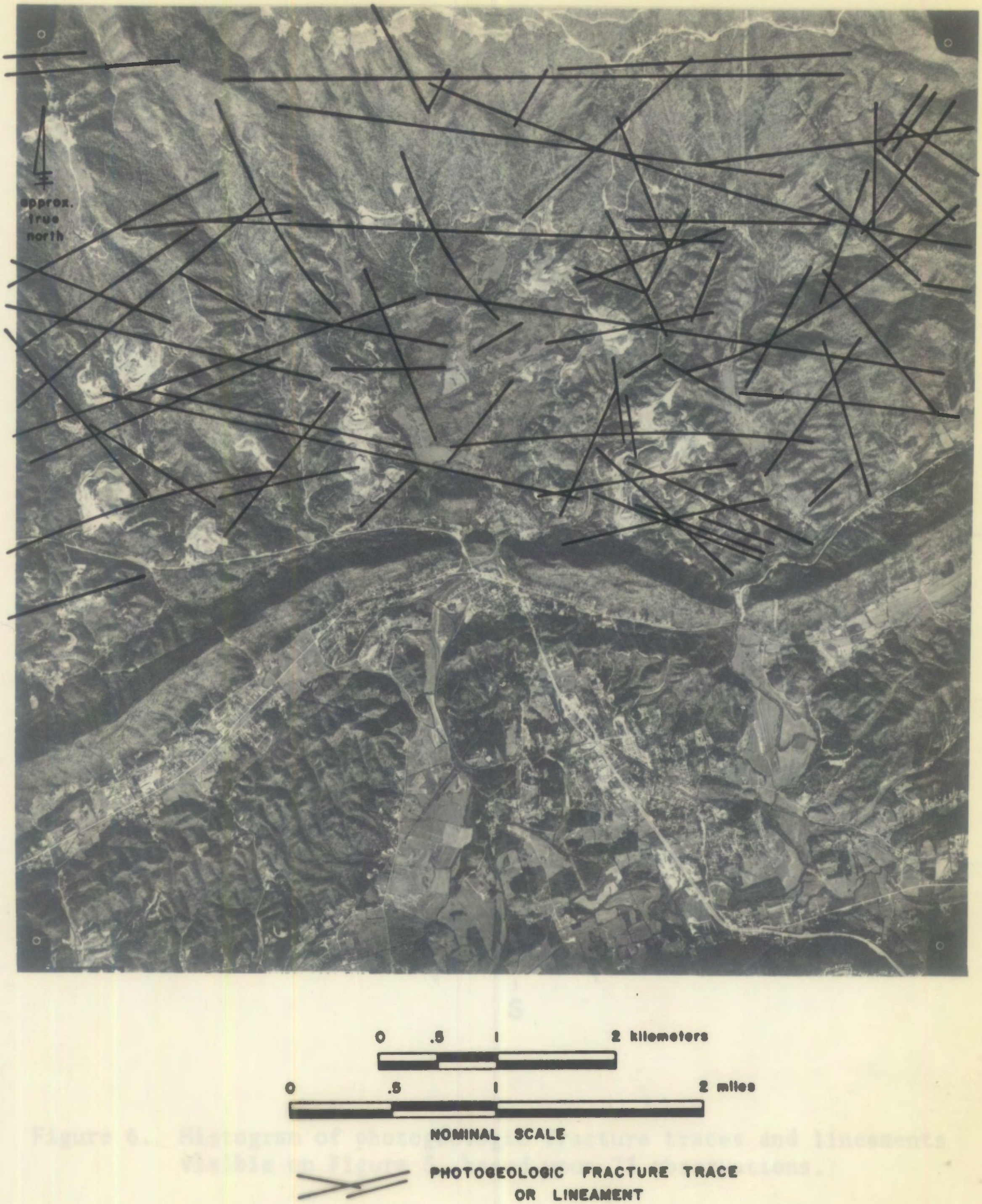

Figure 5. Aerial photograph of Oliver Springs, Walden Ridge, and adjacent Wartburg Basin of the Cumberland Plateau. Photogeologic linear trends visible within the region are represented on transparent overlay.

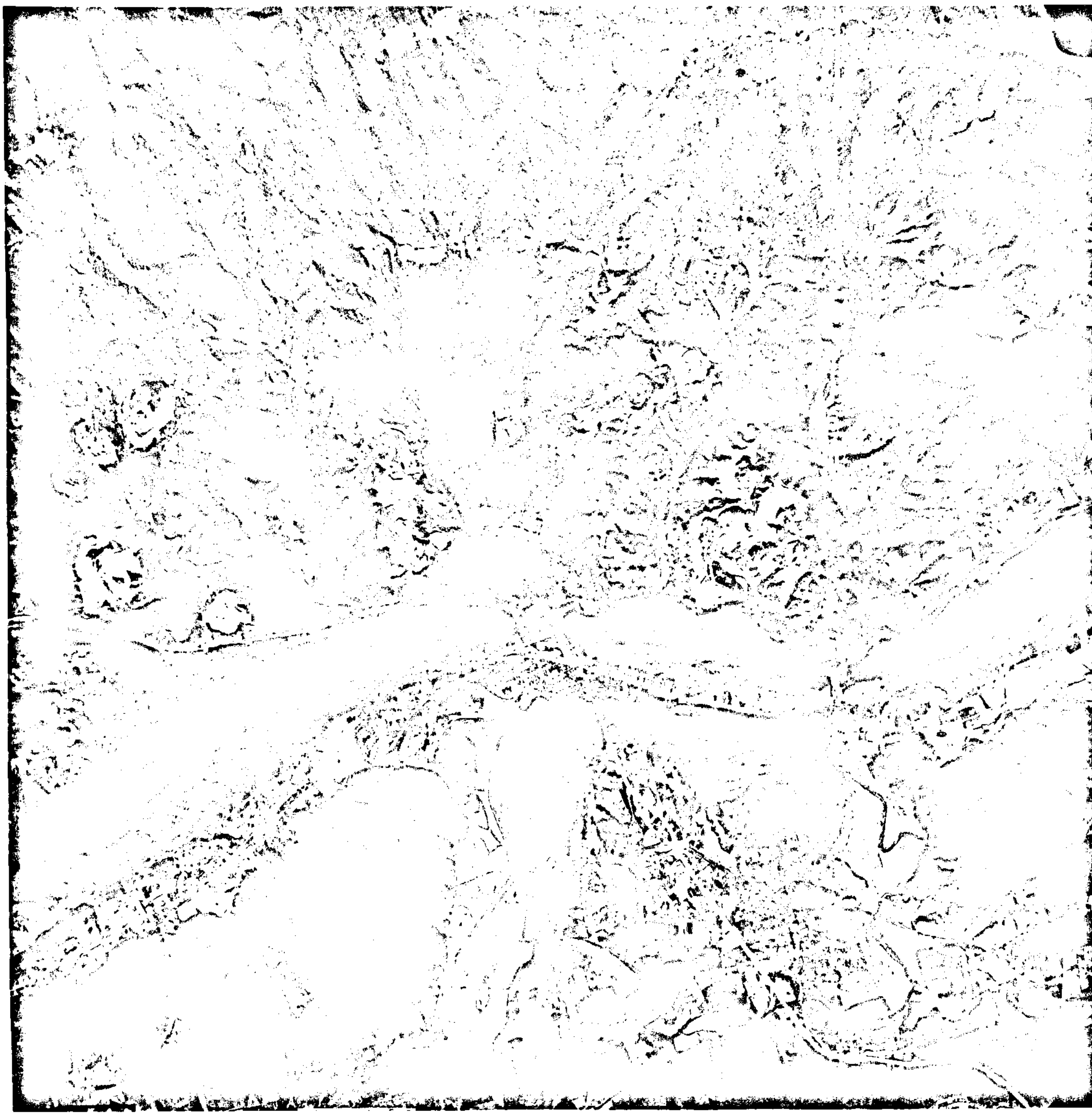

Figure 5. Aerial photograph of Oliver Springs, Walden Ridge, and adjacent Wartburg Basin of the Cumberland Plateau. Photogeologic linear trends visible within the region are represented on transparent overlay.

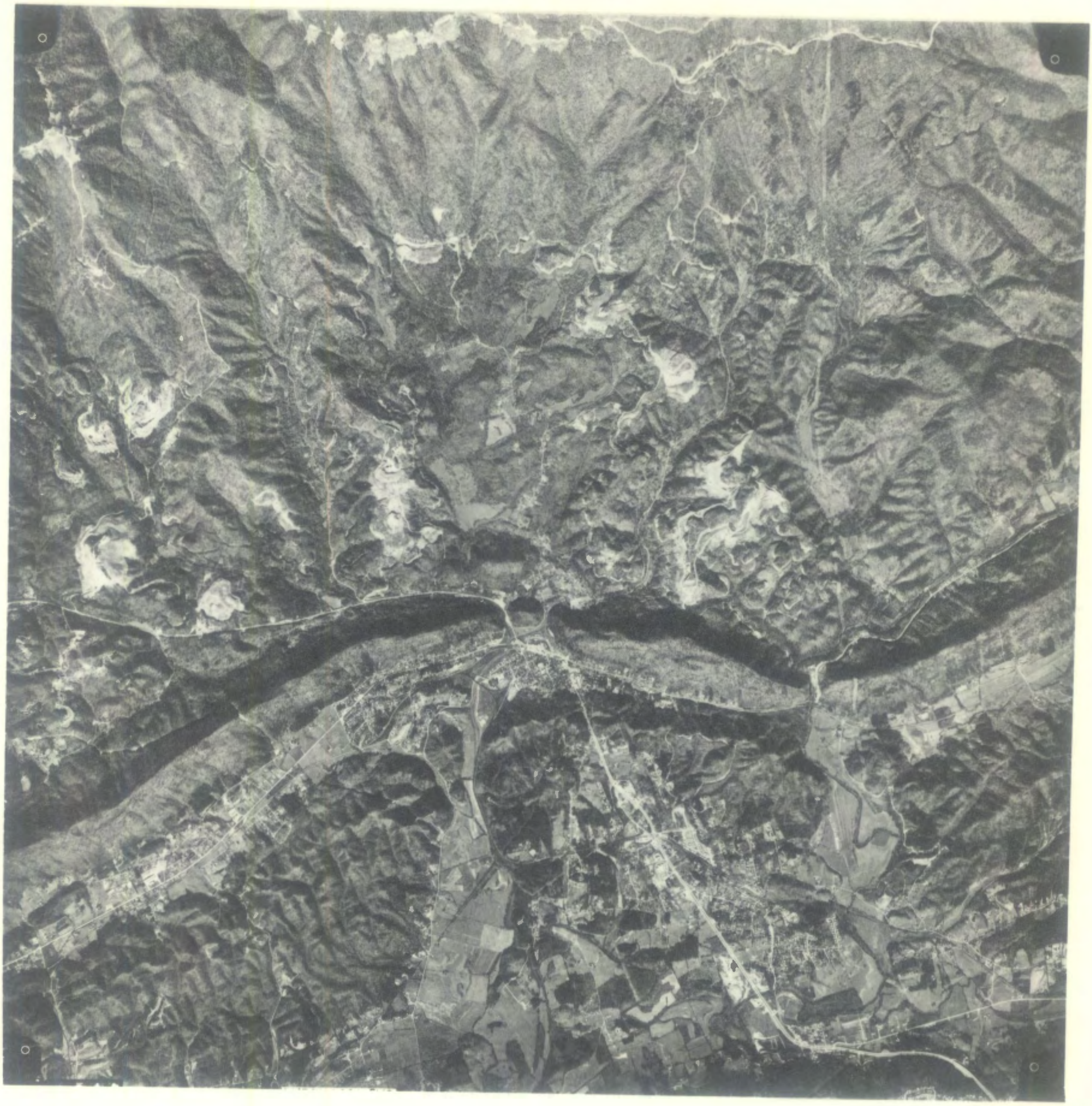

Figure 5. Aerial photograph of Oliver Springs, Walden Ridge, and adjacent Wartburg Basin of the Cumberland Plateau. Photogeologic linear trends visible within the region are represented on transparent overlay.

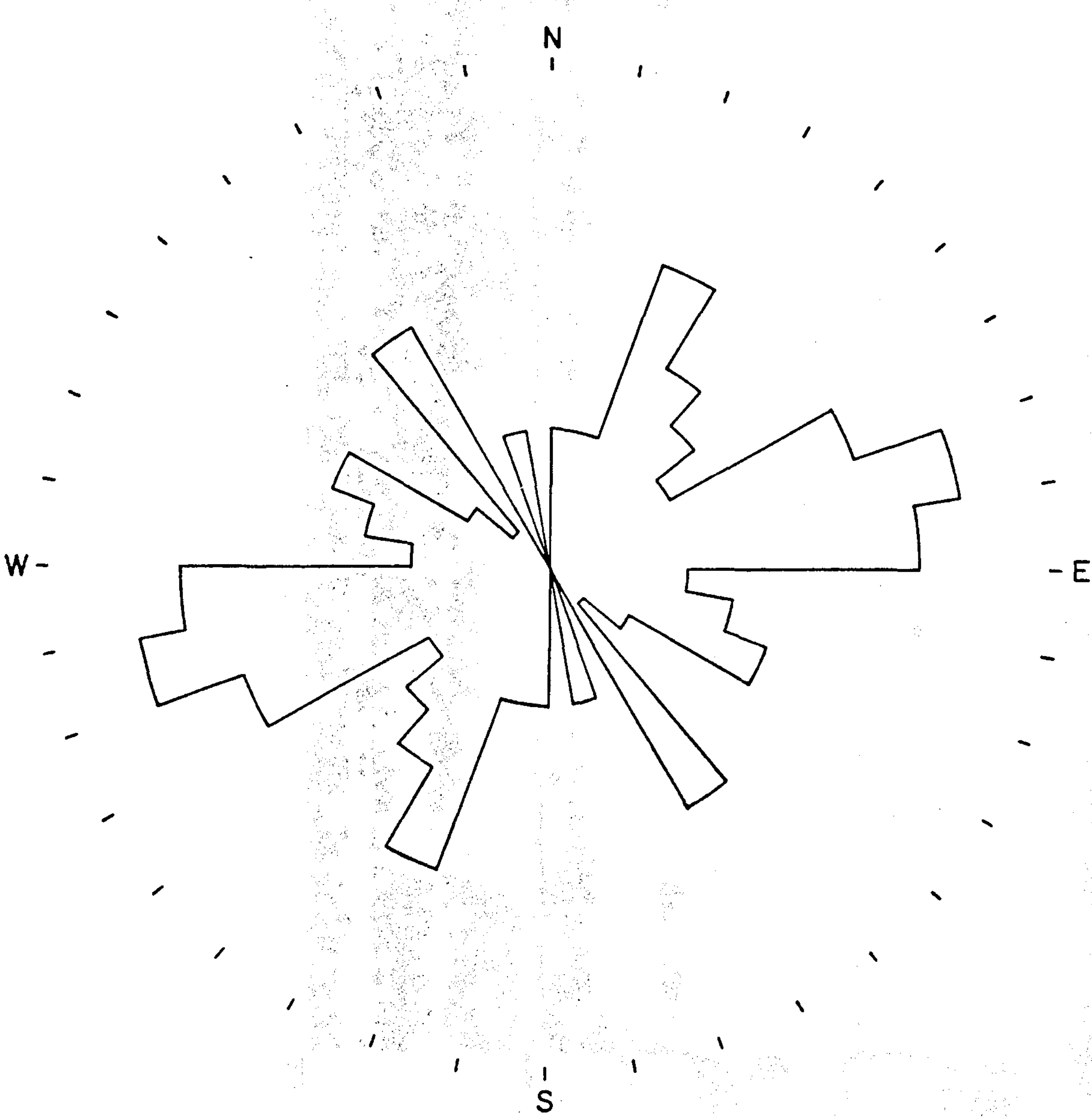

Figure 6. Histogram of photogeologic fracture traces and lineaments visible on Figure 5, based upon 73 observations.

A preferred orientation exists in the northeast quadrant. The fracture trace-lineament maximum is N.70°-80°E. Secondary, tertiary, and quaternary maxima occur at N.20°-30°E., N.30°-40°W., and N.60°-70°W. respectively.

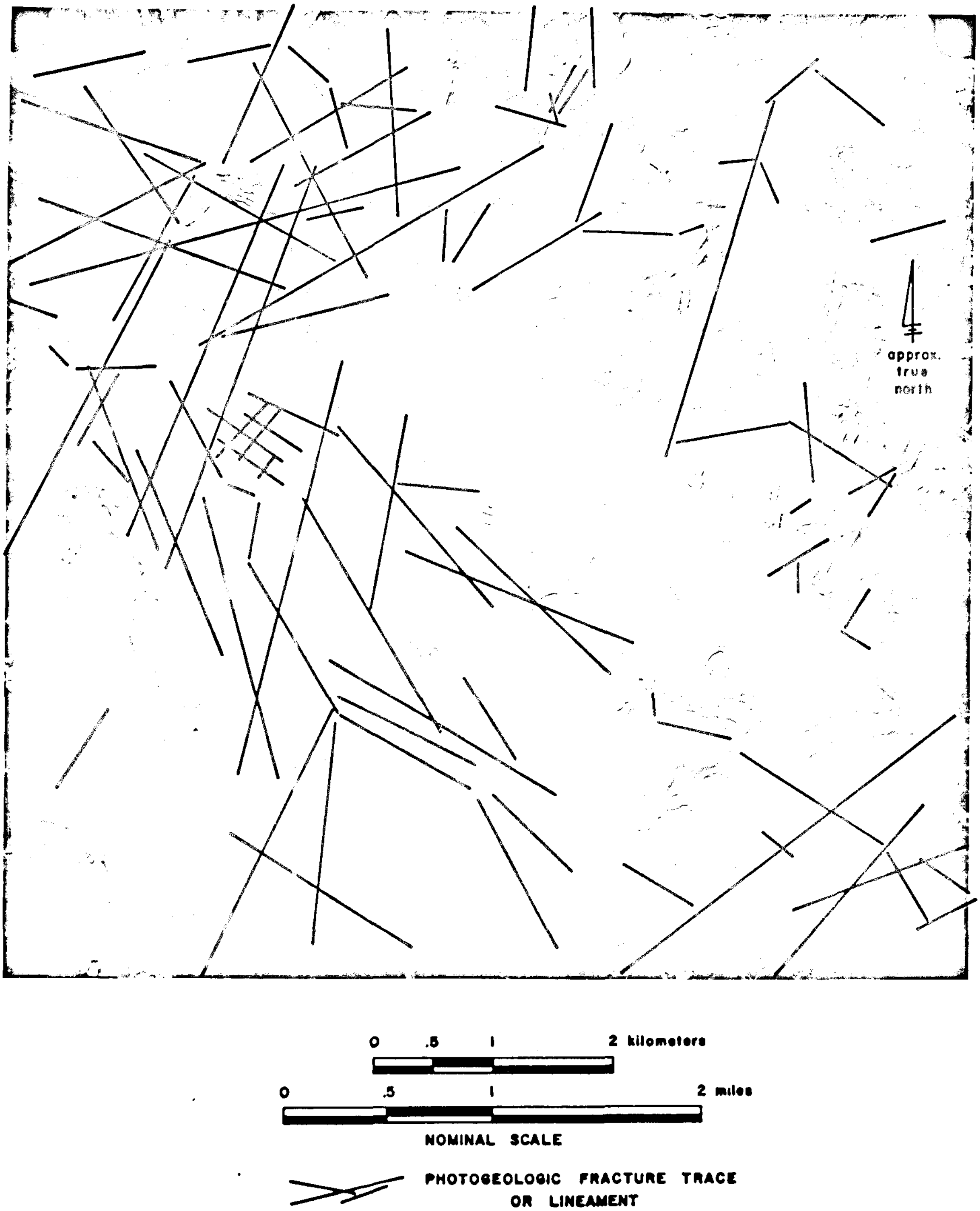

Figure 7. Aerial photograph of the central Wartburg Basin of the Cumberland Plateau. Photogeologic linear trends visible within region are represented on transparent overlay.

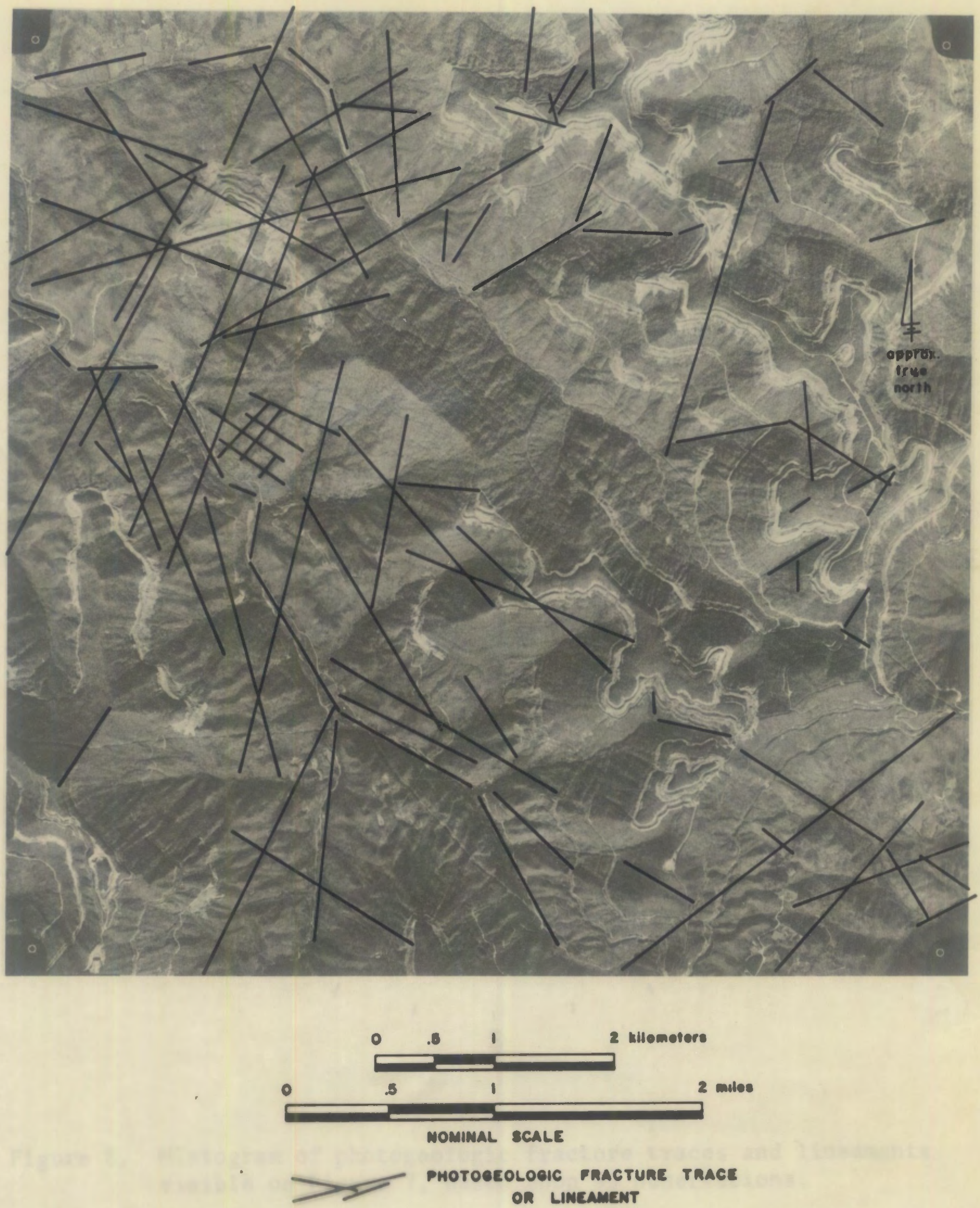

Figure 7. Aerial photograph of the central Wartburg Basin of the Cumberland Plateau. Photogeologic linear trends visible within region are represented on transparent overlay.

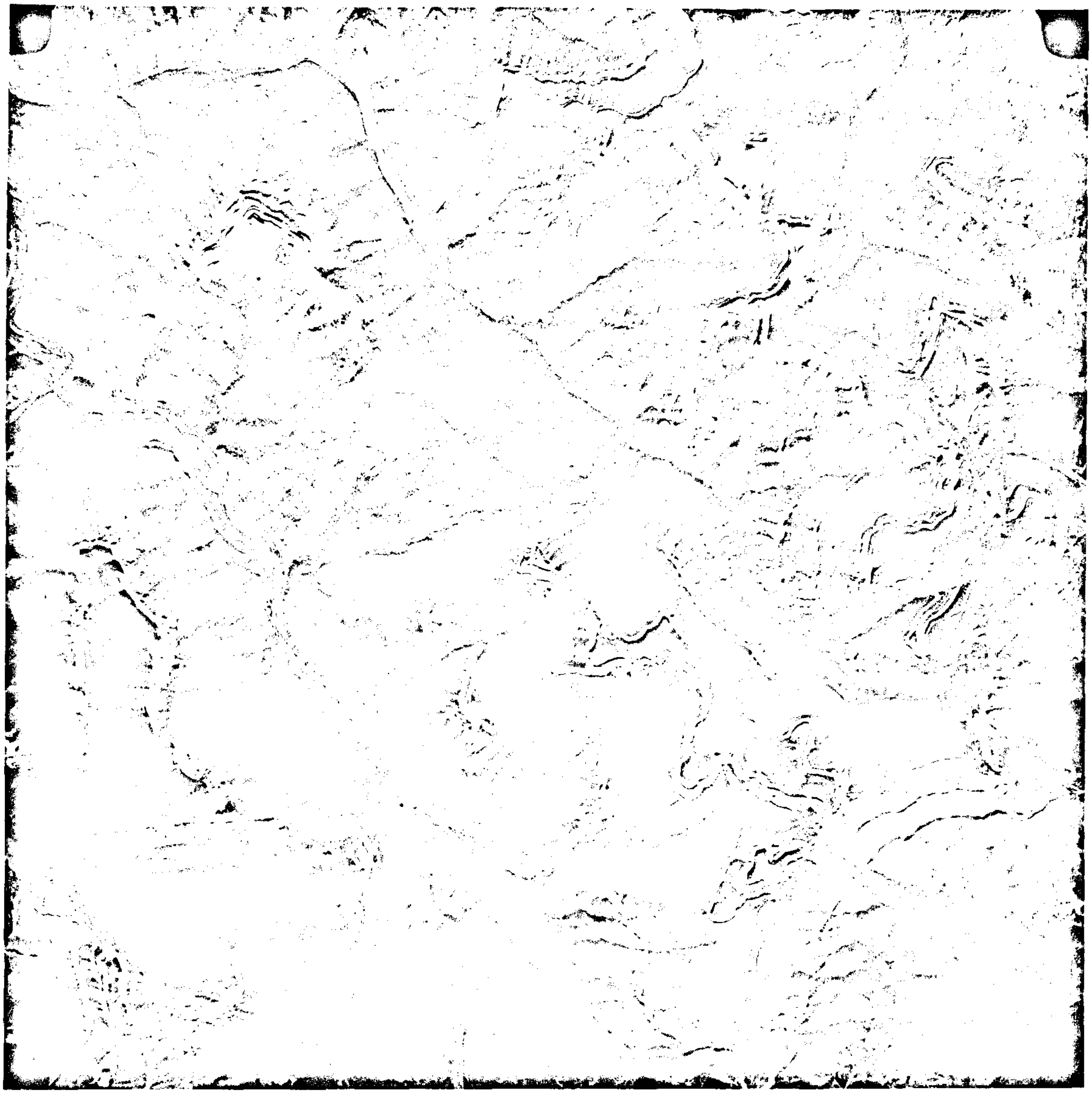

Figure 7. Aerial photograph of the central Wartburg Basin of the Cumberland Plateau. Photogeologic linear trends visible within region are represented on transparent overlay.

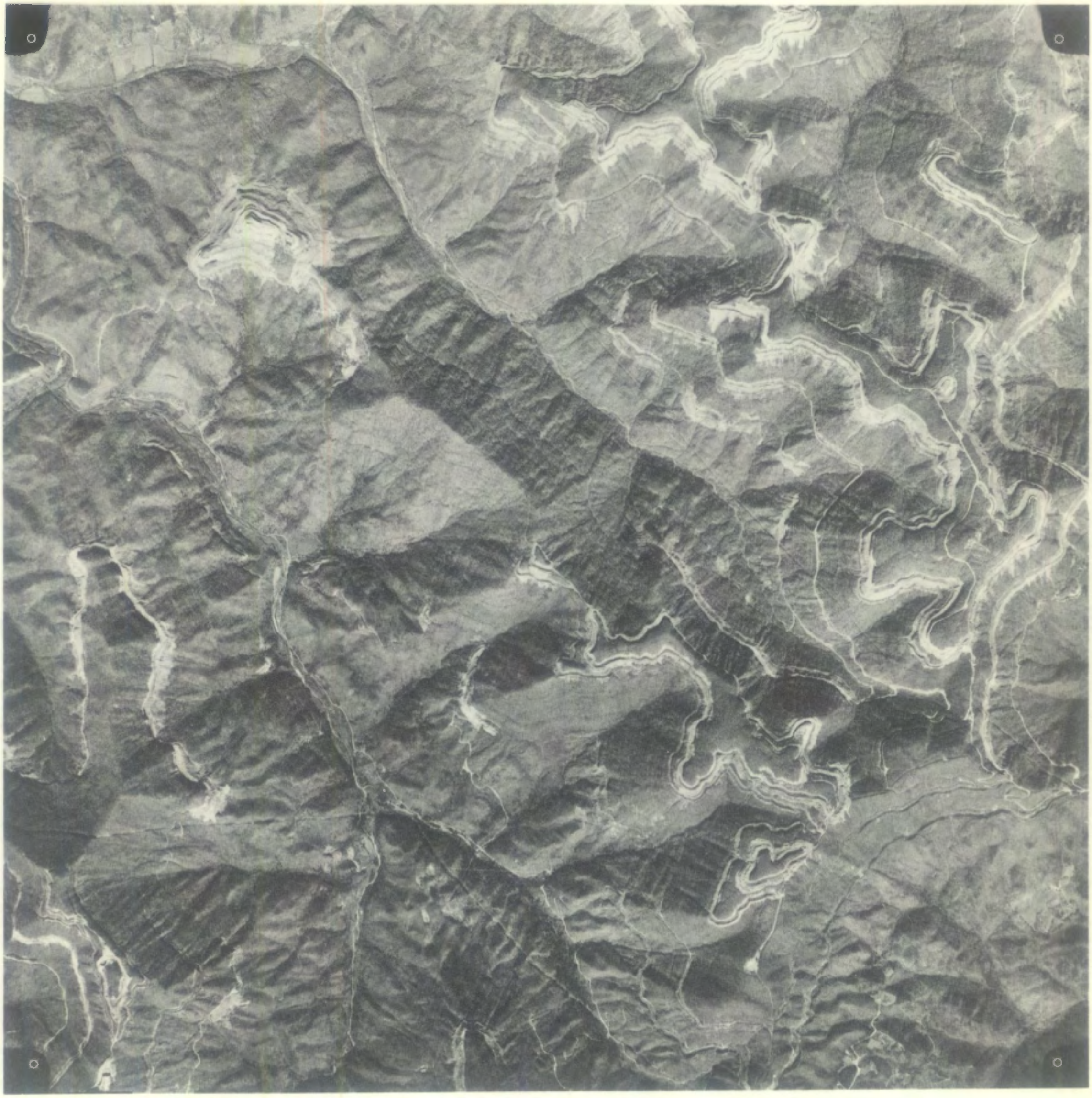

Figure 7. Aerial photograph of the central Wartburg Basin of the Cumberland Plateau. Photogeologic linear trends visible within region are represented on transparent overlay.

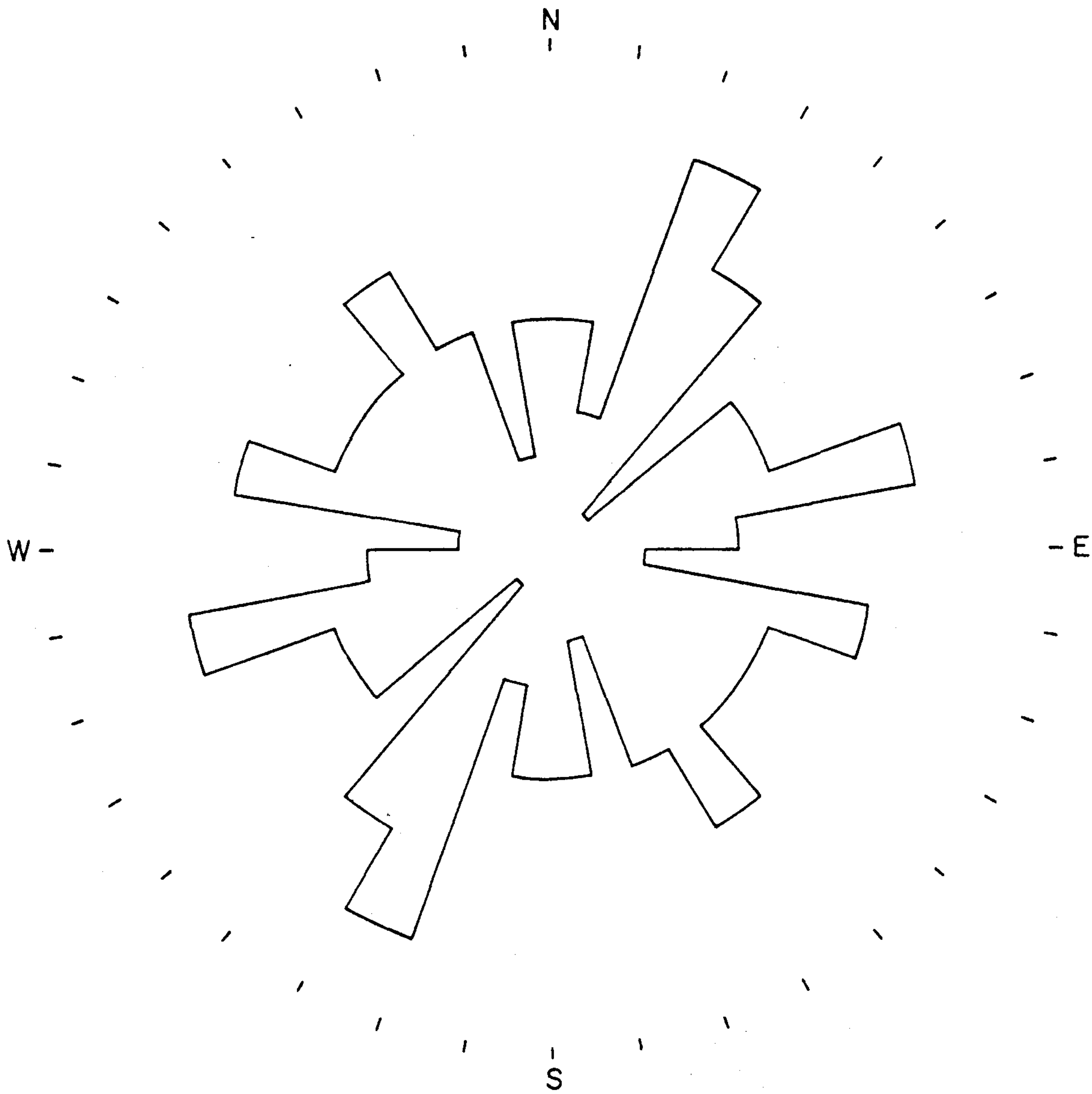

Figure 8. Histogram of photogeologic fracture traces and lineaments visible on Figure 7, based upon 90 observations.

A preferred orientation exists in the northeast quadrant. The fracture trace-lineament maximum is N.20°-30°E. Secondary and tertiary maxima occur at N.70°-80°E., and N.30°-40°W. and N.70°-80°W. respectively.

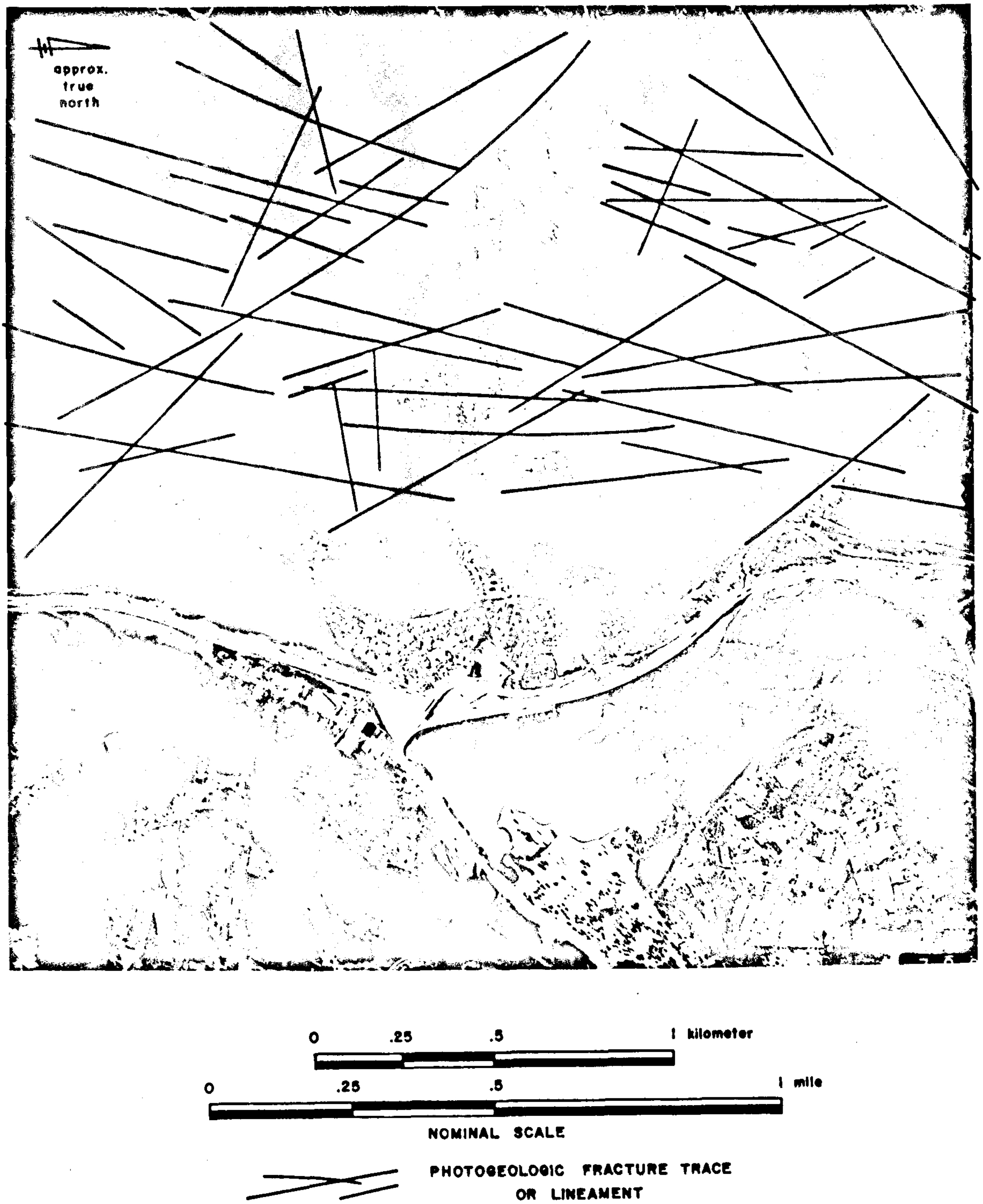

Figure 9. Aerial photograph of Caryville and adjacent Wartburg Basin of the Cumberland Plateau. Photogeologic linear trends visible within the region are represented on transparent overlay.

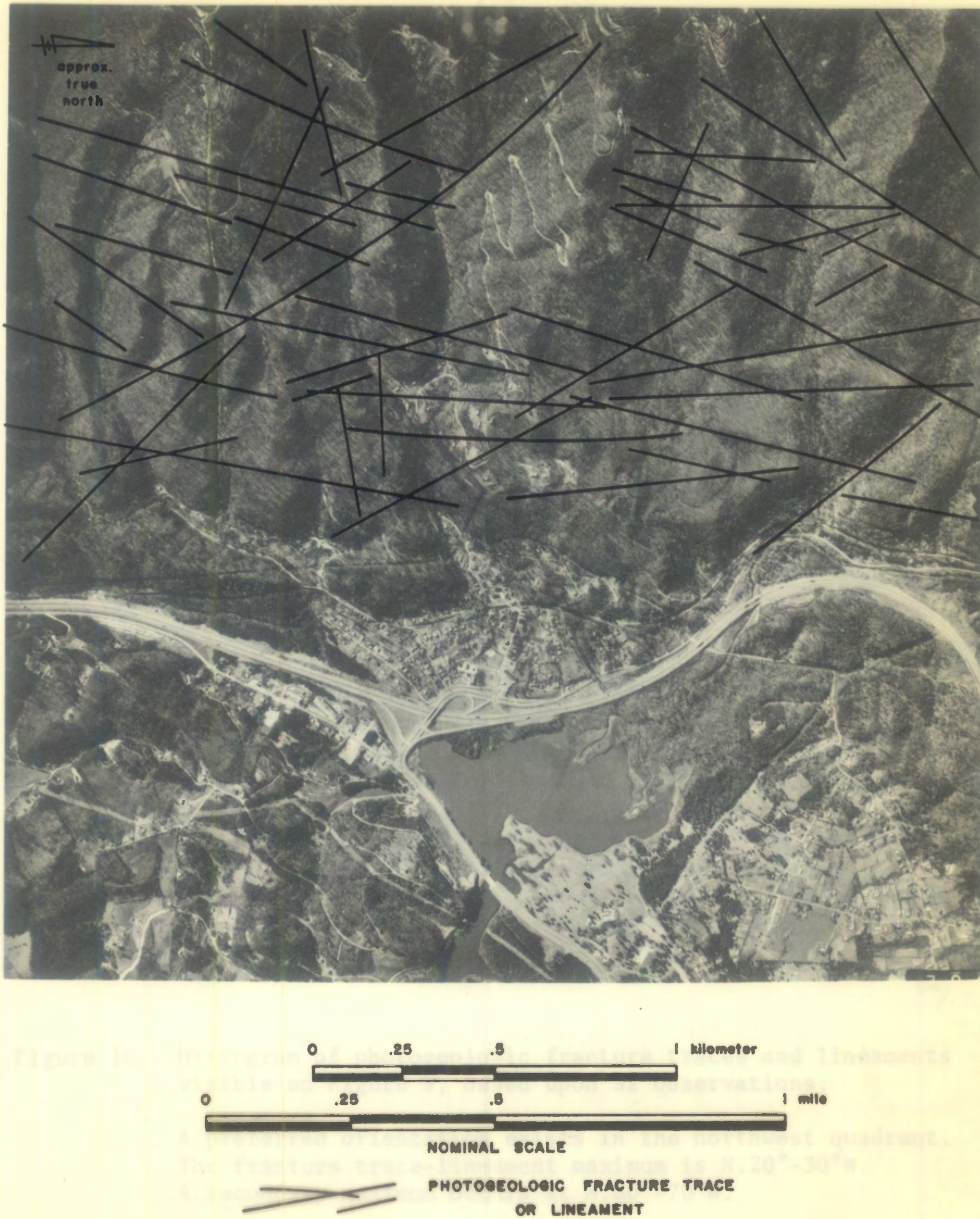

Figure 9. Aerial photograph of Caryville and adjacent Wartburg Basin of the Cumberland Plateau. Photogeologic linear trends visible within the region are represented on transparent overlay.

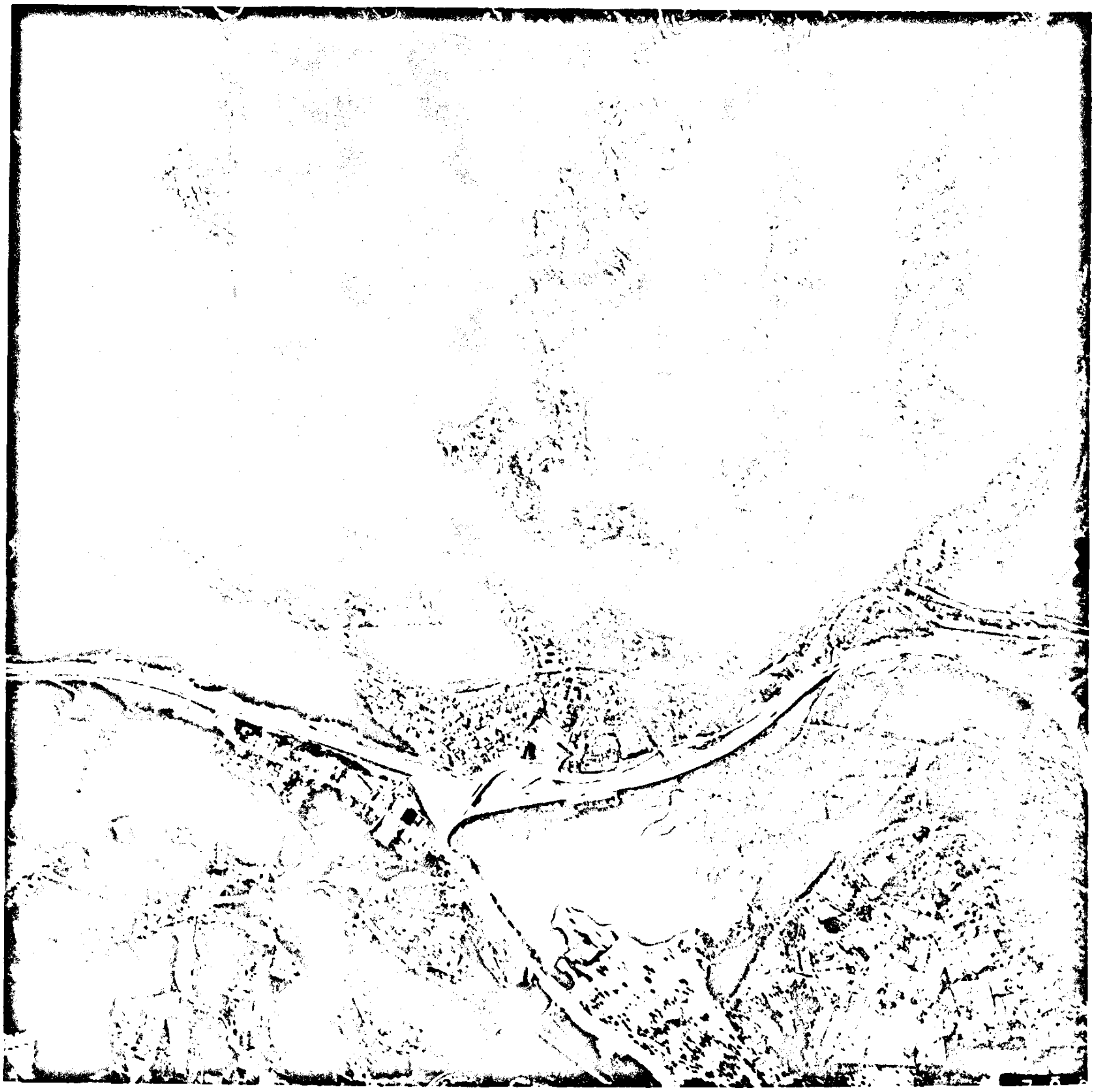

Figure 9. Aerial photograph of Caryville and adjacent Wartburg Basin of the Cumberland Plateau. Photogeologic linear trends visible within the region are represented on transparent overlay.

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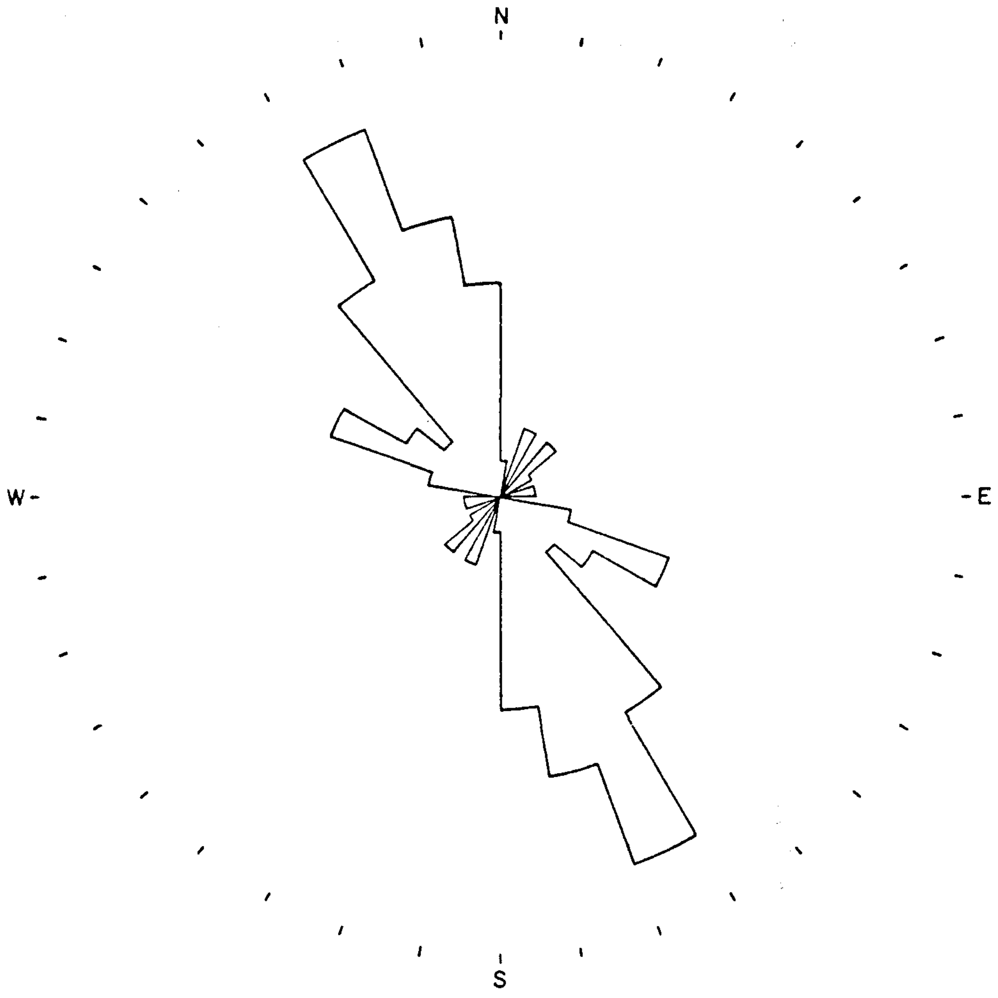

Figure 10. Histogram of photogeologic fracture traces and lineaments visible on Figure 9, based upon 52 observations.

A preferred orientation exists in the northwest quadrant. The fracture trace-lineament maximum is N.20°-30°W. A secondary maximum occurs at N.60°-70°W.

IV. STATISTICAL EVALUATION OF DATA

Data on the individual characteristics of all photogeologic linear features mapped within the project area were compiled and statistically evaluated as a single group.

Statistical Analysis of all Photogeologic Linear Features Mapped within the Research Area

Total number of observations: 590

Composition:

Photogeologic linears composed of a single photointerpretative element: 301 or 51% of total
Photogeologic linears composed of multiple photointerpretative elements: 289 or 49% of total

Photogeologic Linear Expression Elements:

Photogeologic linears of single expression:
- Soil tonal: 34 or 11% of total
- Vegetational: 72 or 24% of total
- Topographic-erosional: 195 or 65% of total

Photogeologic linears of multiple expression:
- Soil tonal + vegetational: 15 or 5% of total
- Soil tonal + topographic-erosional: 192 or 66% of total
- Soil tonal + vegetational + topographic-erosional: 28 or 10% of total
- Vegetational + topographic-erosional: 54 or 19% of total

Continuity:

Continuous photogeologic linears: 239 or 41% of total
Subcontinuous photogeologic linears: 351 or 59% of total

Mappable Lengths:

Photogeologic linears 0.0-0.5 miles in length: 273 or 46% of total
Photogeologic linears 0.5-1.0 miles in length: 183 or 31% of total
Photogeologic linears 1.0-1.5 miles in length: 71 or 12% of total
Photogeologic linears 1.5-2.0 miles in length: 32 or 5% of total
Photogeologic linears 2.0-2.5 miles in length: 15 or 3% of total
Photogeologic linears greater than 2.5 miles in length: 16 or 3% of total

Total number of fractures traces less than one mile in length:
456 or 77% of total
Total number of lineaments one mile or greater in length:
134 or 23% of total

Minimum length of linear feature mapped within research area:
0.08 miles (0.13 kilometers)
Maximum length of linear feature mapped within research area:
5.44 miles (8.76 kilometers)

The research area was divided into three additional statistical subdivisions coincident with areas covered by different scale panchromatic imagery. The subdivisions were necessary due to the unique characteristics of each imagery assemblage which influenced expression, recognition and mapping of fracture traces and lineaments within each specific area.

Statistical Analysis of Photogeologic Linear Features Mapped in Imagery Assemblage One

Date of imagery: November, 1976
Scale of imagery: RF 1:18000, 1" = 1500'
Total number of observations: 52

Little if any foliage existed at the time of photographic exposure. Soil tonal contrasts were the most apparent linear expression element with topographic-erosional alignments of secondary importance. Several 100-200 foot wide zones of possible joint or fault concentration were mapped.

Composition:

Photogeologic linears composed of a single photointerpretative element: 12 or 23% of total
Photogeologic linears composed of multiple photointerpretative elements: 40 or 77% of total

Photogeologic Linear Expression Elements:

Photogeologic linears of single expression:
Soil tonal: 5 or 42% of total
Vegetational: 5 or 42% of total
Topographic-erosional: 2 or 16% of total

Photogeologic linears of multiple expression:
Soil tonal + vegetational: 11 or 28% of total
Soil tonal + topographic-erosional: 8 or 20% of total
Soil tonal + vegetational + topographic-erosional: 19 or 47% of total
Vegetational + topographic-erosional: 2 or 5% of total

Continuity:

Continuous photogeologic linears: 14 or 27% of total
Subcontinuous photogeologic linears: 38 or 63% of total

Mappable Lengths:

Photogeologic linears 0.0-0.5 miles in length: 26 or 50% of total
Photogeologic linears 0.5-1.0 miles in length: 22 or 42% of total
Photogeologic linears 1.0-1.5 miles in length: 4 or 8% of total

Total number of fracture traces less than one miles in length: 48 or 92% of total
Total number of lineaments one mile or greater in length: 4 or 8% of total

Statistical Analysis of Photogeologic Linear Features Mapped in Imagery Assemblage Two

Date of imagery: October, 1973
Scale of imagery: RF 1:20000, 1" = 1667'
Total number of observations: 252

A dense woodland canopy existed at the time of photographic exposure. Vegetational alignments predominated as the major expression element with topographic-erosional alignments of secondary importance. Soil tonal contrasts could not be discerned and were of no consequence with regard to interpretation. Measurable widths consisted of higher standing alignments of timber a single tree crown wide.

Composition:

Photogeologic linears composed of a single photointerpretative element: 191 or 76% of total
Photogeologic linears composed of multiple photointerpretative elements: 61 or 24% of total

Photogeologic Linear Expression Elements:

Photogeologic linears of single expression:
Soil tonal: 0
Vegetational: 190 or greater than 99% of total
Topographic-erosional: 1 or less than 1% of total
Photogeologic linears of multiple expression:
Soil tonal + vegetational: 1 or 2% of total
Soil tonal + topographic-erosional: 5 or 8% of total
Soil tonal + vegetational + topographic-erosional: 3 or 5% of total
Vegetational + topographic-erosional: 52 or 85% of total

Continuity:

Continuous photogeologic linears: 152 or 60% of total
Subcontinuous photogeologic linears: 100 or 40% of total

Mappable Lengths:

Photogeologic linears 0.0-0.5 miles in length: 170 or 67% of total
Photogeologic linears 0.5-1.0 miles in length: 65 or 26% of total
Photogeologic linears 1.0-1.5 miles in length: 12 or 5% of total
Photogeologic linears 1.5-2.0 miles in length: 4 or 2% of total
Photogeologic linears 2.0-2.5 miles in length: 1 or less than 1% of total

Total number of fracture traces less than one miles in length: 235 or 93% of total
Total number of lineaments one mile or greater in length: 17 or 7% of total

Statistical Analysis of Photogeologic Linear Features Mapped on Imagery Assemblage Three

Date of imagery: November, 1974
Scale of imagery: RF 1:36000, 1" = 3000'
Total number of observations: 286

Soil tonal and vegetational alignments were indistinguishable from one another. It was concluded from the date of photographic exposure that foliage was not a significant interpretation factor and most tonal alignments were due to soil tonal contrasts. Soil tonal alignments in conjunction with topographic-erosional alignments were the most important linear expression elements.

Composition:

Photogeologic linears composed of a single photointerpretative element: 98 or 34% of total
Photogeologic linears composed of multiple photointerpretative elements: 188 or 66% of total

Photogeologic Linear Expression Elements:

Photogeologic linears of single expression:
Soil tonal: 29 or 30% of total
Vegetational: 0
Topographic-erosional: 69 or 70% of total
Photogeologic linears of multiple expression:
Soil tonal + vegetational: 3 or 2% of total
Soil tonal + topographic-erosional: 179 or 95% of total
Soil tonal + vegetational + topographic-erosional: 6 or 3% of total
Vegetational + topographic-erosional: 0

Continuity:

Continuous photogeologic linears: 73 or 26% of total
Subcontinuous photogeologic linears: 213 or 74% of total

Mappable Lengths:

Photogeologic linears 0.0-0.5 miles in length: 77 or 27% of total
Photogeologic linears 0.5-1.0 miles in length: 96 or 34% of total
Photogeologic linears 1.0-1.5 miles in length: 55 or 19% of total
Photogeologic linears 1.5-2.0 miles in length: 28 or 10% of total
Photogeologic linears 2.0-2.5 miles in length: 14 or 5% of total
Photogeologic linears greater than 2.5 miles in length: 16 or 5% of total

Total number of fracture traces less than one mile in length: 173 or 60% of total
Total number of lineaments one mile or greater in length: 113 or 40% of total

V. HISTOGRAMS

The research area was divided into nine geographic subdivisions (Figure 11). Criteria used as a basis for division included:

1. areas of approximate equal fracture trace and lineament density,

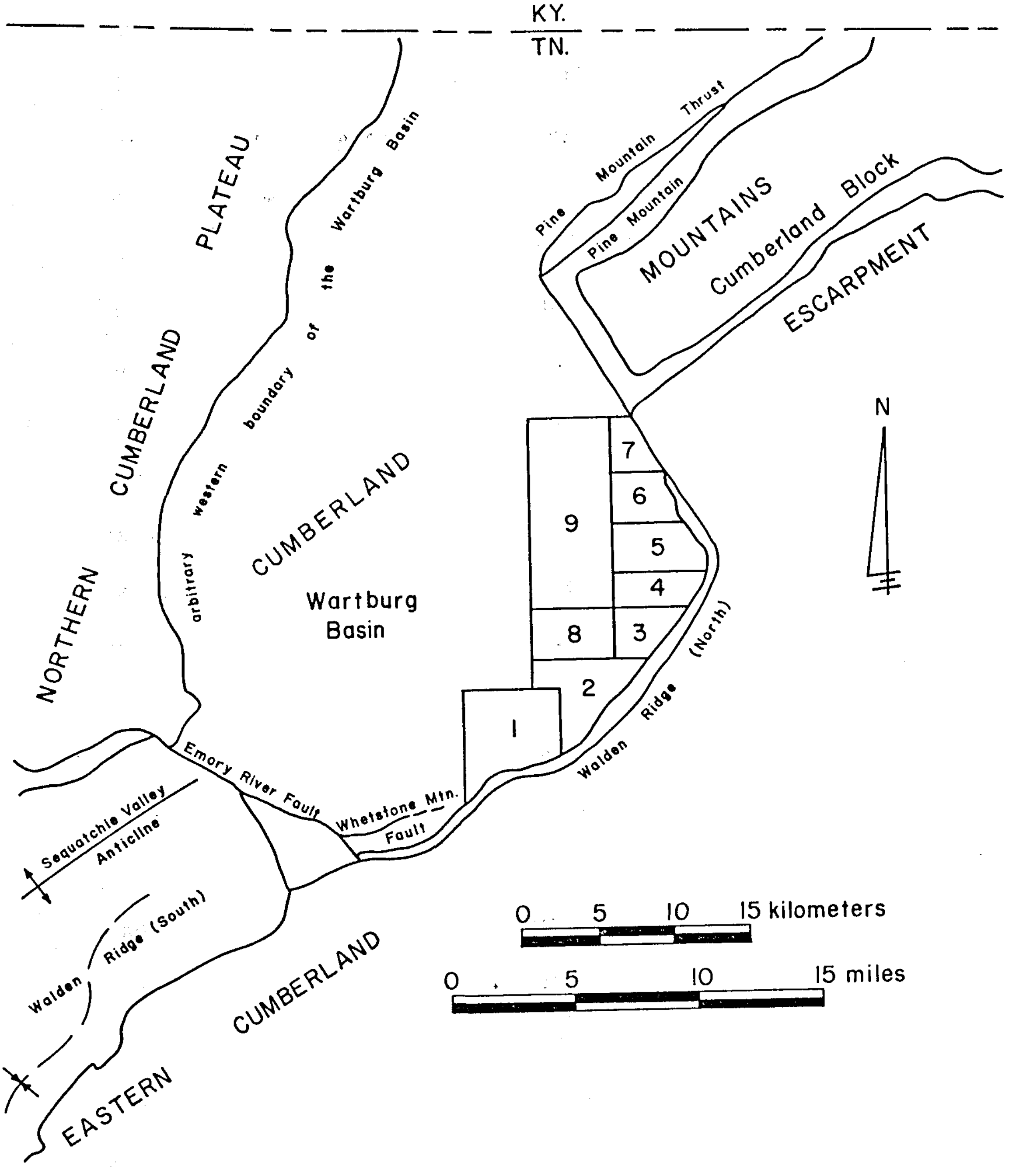

Figure 11. Location and extent of geographic subdivisions used for statistical evaluation of photointerpretative data.

2. groups of photogeologic linear features related to a particular imagery type,
3. locations of fracture trace and lineament clusters with regard to the regional structural framework.

Histograms summarizing strike orientations of photogeologic linears were prepared for each subdivision (Appendix A, Figures A1-A9). Comparison of data obtained from individual localities enabled the evaluation of orientation frequencies and trends on a regional scale.

The nine geographic subdivisions used in the statistical evaluation of the research area were divisible into two major classes: those localities adjacent to more tectonically influenced areas marginal to the Jacksboro fault and the leading edge of the Cumberland Escarpment (Walden Ridge), and those areas centrally located on the plateau.

Histograms of subdivisions 1 and 2 bordering the southeastern margin of the research area exhibit orientations subparallel to the northeastern strike of Walden Ridge. Northward, orientations in areas 3-6 gradually swing to the northwest with maxima varying between N.10°E. and N.10°W. The northwestern trend is increasingly evident and subparallel to the Jacksboro fault in area 7. Histograms of areas 8 and 9 on the central plateau have preferred orientations to the northeast which appear independent of the orientations previously discussed.

CHAPTER IV

FIELD DATA ACQUISITION PHASE OF RESEARCH

The general nature of the research area imposed severe restrictions on the field investigation. Factors which influenced the selection, spacing, and location of field data acquisition sites included the scarcity of natural bedrock exposures, rugged topography, and limited access to areas of known fracture trace and lineament intersection. The research area is covered by a deeply-weathered regolith and dense vegetation that restricted measurement of fracture orientations to bedrock exposures along road cuts and in strip-mine highwalls.

I. PROCEDURE

Data on bedrock fracture orientations were acquired from seventeen localities in the research area (see Plate I for numbered locations). Site selection included locations not associated with any fracture trace or lineament as well as areas of bedrock exposure known to be intersected by photogeologic linear features. At each location the following data were acquired: the surface nature of the fracture, fracture termination type, height and width of fracture, and the spacing between members belonging to distinct fracture sets. The most significant data obtained during the field investigation concerned the attitude of each fracture and the lithology or lithologies in which it was observed. This information was primarily used in the analysis of specific cases of bedrock fracture-photogeologic linear correlation.

II. STATISTICAL EVALUATION OF FIELD DATA

Data on individual characteristics of bedrock fractures were statistically compiled and evaluated.

Statistical Analysis of Bedrock Fractures Observed within the Research Area

Total number of observations: 193

Fracture Type:

Bedrock joints: 179 or 93% of total
Coal cleats: 14 or 7% of total

Lithology in Which Fracture was Observed:

Sandstone: 71 or 37% of total
Siltstone: 40 or 21% of total
Shale: 39 or 20% of total
Sandstone-shale (interbedded): 29 or 15% of total
Coal: 14 or 7% of total

Dip Variation:

90°-81°: 128 or 66% of total
80°-71°: 54 or 28% of total
Less than 71°: 11 or 6% of total

All observed fractures were either joints or coal cleats. Orientation data of coal cleats were of little significance for two reasons. First, coal cleat orientations represented a small percentage of the total number of observations. Secondly and most important, fracture orientations measured in coal were generally restricted to the coal lithology and not observed to extend into the underlying or overlying rock units. Therefore, joints in coal are not usually expressed at the surface.

Fractures measured within the research area were vertical or steeply inclined.

III. HISTOGRAMS

The seventeen localities of data acquisition were grouped into five general areas to facilitate the evaluation of data. Fracture strike orientations are summarized by histograms (Appendix B, Figures B1-B5). The data represents the strike of individual fractures belonging to distinct fracture sets that have similar orientations.

IV. SPECIFIC EXAMPLES OF PHOTOGEOLOGIC LINEAR AND BEDROCK FRACTURE CORRELATION

Five specific localities were investigated in an attempt to establish a direct correlation between the strikes of bedrock fractures and photogeologic linear features. Of particular interest were locations where photogeologic fracture traces or lineaments intersected outcrops observed on the imagery. Fracture zones recognizable in the field which might possibly be discerned on aerial photographs often possess the following definitive characteristics:

1. a zone of joint or fault concentration,
2. a linear trend of topographic depression or subsidence,
3. an area of groundwater seepage and luxuriant foliage,
4. a zone of anomalously intense weathering.

<u>Specific Example 1—Site 5</u>

Location: Cross Mountain, Anderson County, Lake City quadrangle
Approximate elevation: 3300'
Site placement: strip-mine highwall

The site is a strip-mine highwall approximately 4500 feet in length. Bedrock fracture orientations were recorded at 500 foot intervals along the exposure. Station G (Figure 12) coincides with the intersection of a photogeologic fracture trace that trends N.58°W. Two distinct fracture sets were observed in interbedded shales and sandstones 1", 4", and 18" in thickness. The attitude of one set is N.62°W./90 with a spacing of 50" between fractures.

Specific Example 2—Site 9

Location: Vowell Mountain, Anderson County, Lake City quadrangle
Approximate elevation: 2300'
Site placement: strip-mine highwall

The site is a strip-mine highwall currently being excavated for the purpose of mining (Figure 13). The exposure is in clay, shale, sandstone, and coal and is deeply weathered. It is intersected by a photogeologic linear that trends N.05°W. Several distinct bedrock fracture orientations were recorded at the site including sets with attitudes of N.10°W/90, N.06°W./82 NE, and N.06°W/79 NE (coal cleat). The spacing between fractures belonging to the sets is 13", 7", 3"; 12", 3"; and 3" respectively.

Specific Example 3—Site 12

Location: Cross Mountain, Campbell County, Duncan Flats quadrangle
Approximate elevation: 3200'
Site placement: strip-mine highwall

The site is a strip-mine highwall approximately 2000 feet in length. Bedrock fracture orientations were recorded at 300 foot intervals along the exposure. Station A (Figure 14) is intersected by a photogeologic fracture trace that trends N.65°W. Several fracture sets were observed in thick sandstone and interbedded shale at the site including one with

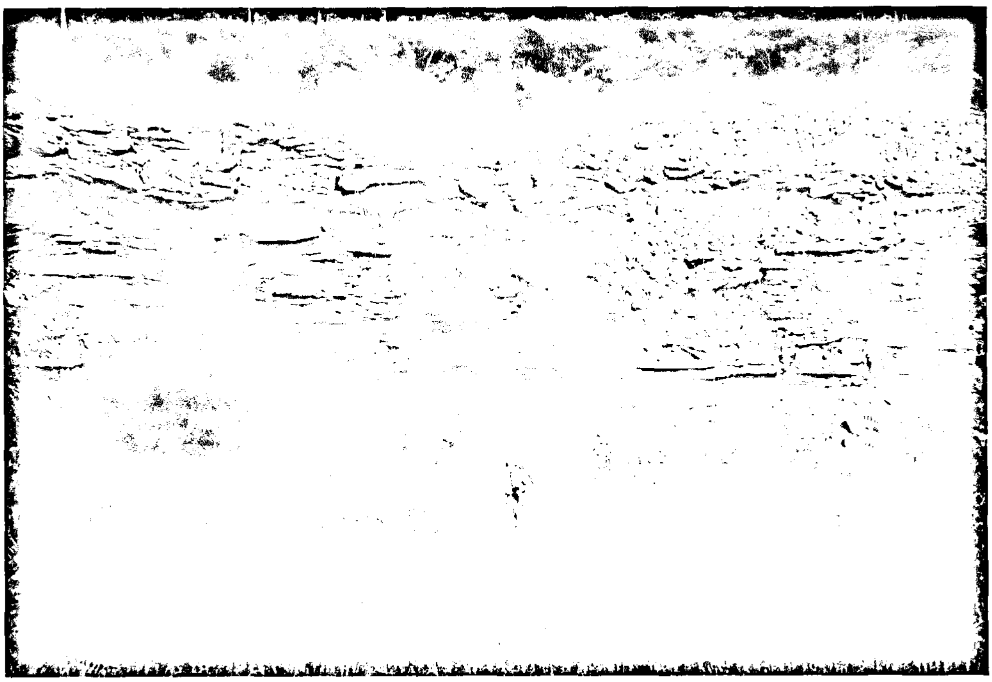

Figure 12. Specific Example 1, Site 5.

The site is characterized by a zone of topographic depression and water seepage associated with bedrock fractures trending N.62°W.

Figure 12. Specific Example 1, Site 5.

The site is characterized by a zone of topographic depression and water seepage associated with bedrock fractures trending N.62°W.

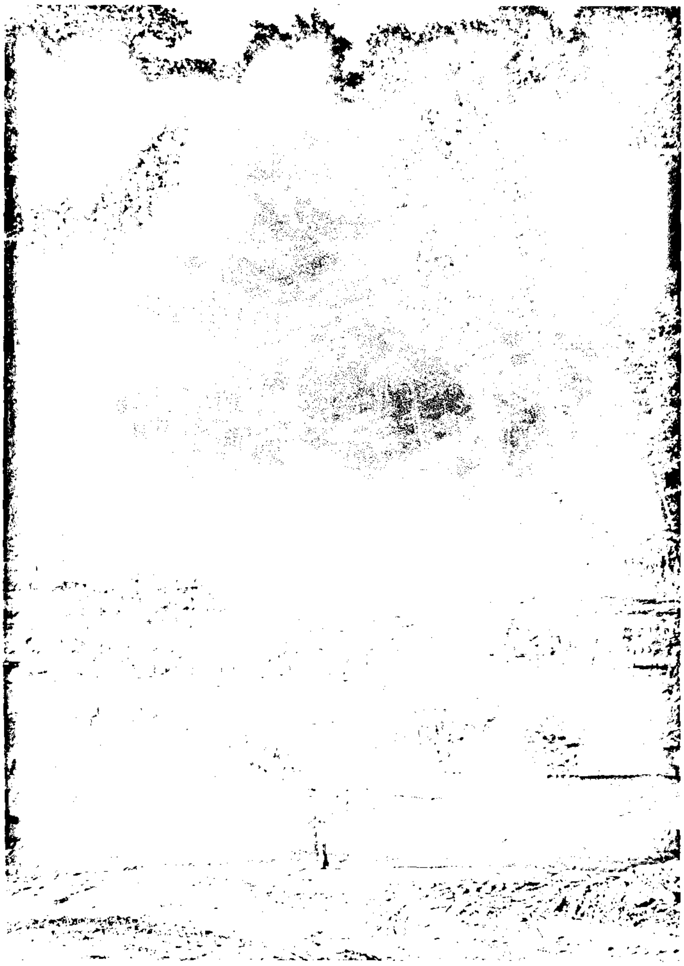

Figure 13. Specific Example 2, Site 9.

The site is characterized by an area of topographic depression and water seepage associated with bedrock fracture sets that trend N.06°W. and N.10°W.

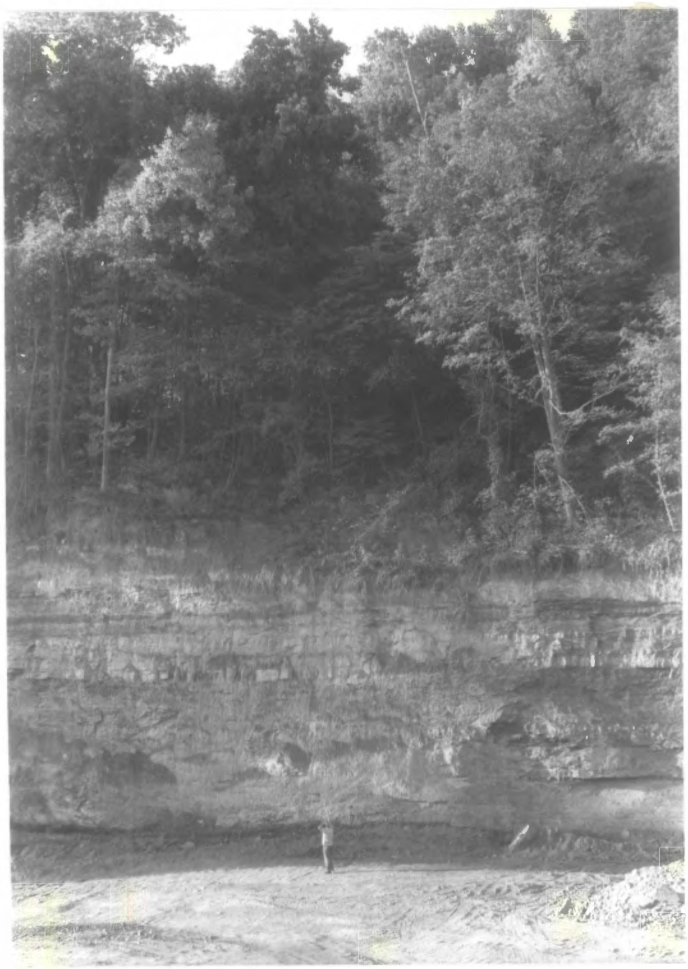

Figure 13. Specific Example 2, Site 9.

The site is characterized by an area of topographic depression and water seepage associated with bedrock fracture sets that trend N.06°W. and N.10°W.

Figure 14. Specific Example 3, Site 12.

The site is characterized by a zone of topographic depression and multiple fractures that trend N.65°W.

Figure 14. Specific Example 3, Site 12.

The site is characterized by a zone of topographic depression and multiple fractures that trend N.65°W.

attitude N.65°W./80 SW. The spacing between fractures belonging to this set is 6' and 12'.

Specific Example 4—Site 14

Location: Red Oak Mountain, Anderson-Campbell County line, Duncan Flats quadrangle
Approximate elevation: 2660'
Site placement: strip-mine road cut

The site is a strip-mine road cut through a topographic saddle along the crest of Red Oak Mountain (Figure 15). The location is intersected by three photogeologic linears that trend N.62°W., N.72°E, and N.22°E. Fracture sets with attitudes of N.58°W./88 SW, N.71°E./84 SE, and N.20°E./88 SE were observed in siltstone and shale at the site (Figure 16). The spacing between fractures belonging to the individual sets is 8'; 18", 8", 4", 3"; and 12", 4" respectively. Several zones of fractures up to 61" in width are associated with the set trending N.58°W.

Specific Example 5—Site 15

Location: Red Oak Mountain, Anderson County, Duncan Flats quadrangle
Approximate elevation: 2400'
Site placement: strip-mine highwall

The site is a strip-mine highwall approximately 300 feet in length (Figure 17). A photogeologic linear trending N.72°E. intersects this location as well as site 14. Multiple bedrock fracture sets were observed in siltstone including a set with attitude N.70°E./88 SE. The spacing between major fracture belonging to this set averages 25'.

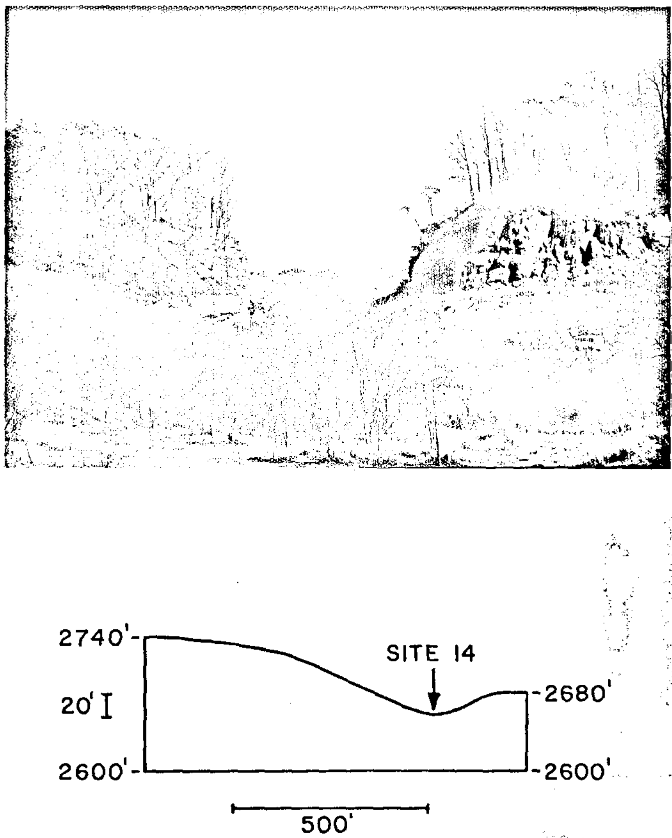

Figure 15. Northeast view of Specific Example 4, Site 14 along the crest of Redoak Mountain.

The topographic profile of the area prior to road cut excavation shows the slope of the ridge crest towards the site of photogeologic linear intersection. The site is characterized by multiple fracture sets in an area of topographic depression.

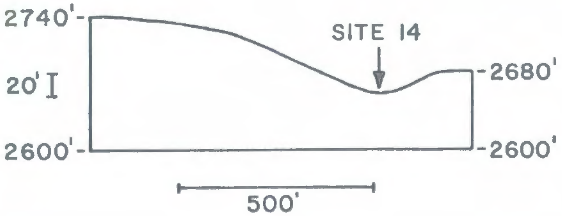

Figure 15. Northeast view of Specific Example 4, Site 14 along the crest of Redoak Mountain.

The topographic profile of the area prior to road cut excavation shows the slope of the ridge crest towards the site of photogeologic linear intersection. The site is characterized by multiple fracture sets in an area of topographic depression.

(a) Southeast facing exposure.

(b) Northwest facing exposure.

Figure 16. Joints exposed in strip-mine road cut at Site 14, Specific Example 4.

The site is characterized by several zones of joints up to 61" in width that trend N.58°W.

(a) Southeast facing exposure.

(b) Northwest facing exposure.

Figure 16. Joints exposed in strip-mine road cut at Site 14, Specific Example 4.

The site is characterized by several zones of joints up to 61" in width that trend N.58°W.

Figure 17. Specific Example 5, Site 15.

The site is characterized by a distinct set of bedrock fractures that trend N.70°E.

Figure 17. Specific Example 5, Site 15.

The site is characterized by a distinct set of bedrock fractures that trend N.70°E.

CHAPTER V

RESULTS AND OBSERVATIONS

The data from each phase of investigation were evaluated to determine if a correlation between photogeologic linear directions and bedrock fracture orientations existed. The evaluation involved a comparison of orientation frequency diagrams on a regional scale as well as direct correlation of photogeologic linears with ground-observed fractures.

I. COMPARISON OF GROUND-OBSERVED AND PHOTO-SCALE FRACTURE PATTERNS

The seventeen sites of field data acquisition were placed into five groups on the basis of their geographic proximity to each other. Each group represented an area that generally corresponded to one of the geographic subdivisions utilized in the photointerpretative phase of research. Histograms of bedrock fracture orientations and photogeologic linear directions were compared in each area. The intent of the comparison was the identification of trend similarities of orientations rather than direct one-to-one correlations.

Area 1 (Appendix B, Figure B1)—Subdivision 7 (Appendix A, Figure A7)

A preferred orientation of photogeologic fracture traces and lineaments exists in the northwest quadrant with a maximum at N.20°-30°W. and a variance around this maximum from N.10°W. to N.40°W. Preferred orientations of ground-observed fractures are found in the northwest and northeast quadrants at N.30°-40°W. and N.60°-70°E. A comparison of histograms reveals similar trends in orientation patterns in the northwest quadrant. The marked absence of any significant photogeologic trends to the northeast indicates that bedrock fractures with northeast orientations are not important as elements of surficial fracture expression.

Area 2 (Appendix B, Figure B2)—Subdivision 5 (Appendix A, Figure A5)

A comparison of histograms indicates a difference in orientation patterns. A preferred orientation of photogeologic features exists in the northeast quadrant at N.0°-10°E. with a variance from this maximum to N.20°W. A similar trend in ground observed fractures is expressed as a tertiary maximum at N.0°-10°W. Primary bedrock fracture trends in the northeast and northwest quadrants at N.40°-50°E. and N.30°-40°W. are not evident in the photogeologic orientation histogram. A secondary photogeologic maximum at N.80°-90°W. appears related to a primary bedrock fracture trend at N.70°-80°W.

Area 3 (Appendix B, Figure B3)—Subdivision 8 (Appendix A, Figure A8)

Comparison of histograms indicates two trends that are roughly similar and may be related. Preferred orientations of bedrock fractures are at N.20°-30°E. and N.50°-60°E. Photogeologic orientation trends occur at N.10°-20°E. and N.40°-50°E. Orientation trends in the northwest quadrant of both histograms are dissimilar and do not appear related.

Area 4 (Appendix B, Figure B4)—Subdivision 1 (Appendix A, Figure A1)

Two similar orientation trends are evident on the histograms. A preferred orientation of ground-observed fractures exists in the northwest quadrant at N.60°-70°W. This trend corresponds to a quaternary maximum with the same azimuth interval. Similarly, a tertiary bedrock fracture maximum at N.70°-80°E. corresponds to the preferred orientation of photogeologic linears in the northeast quadrant at N.70°-80°E.

Area 5 (Appendix B, Figure B5)—Subdivision 9 (Appendix A, Figure A9)

Histograms of bedrock fracture orientations and photogeologic linear feature trends are markedly similar. In each histogram a preferred orientation exists in the northeast quadrant. The ground-observed fracture maximum is at N.20°-30°E. and appears related to the photogeologic fracture trace and lineament maximum at N.30°-40°E. Other trends that are similar occur at N.0°-10°E., N.30°-40°W., and N.70°-80°W.

The similarity or dissimilarity of orientation patterns on corresponding histograms can be accounted for. Each of the five areas of field investigation corresponded to a geographic subdivision of photointerpretation. These subdivisions were in turn associated with a particular imagery type with its own unique characteristics.

In areas 1 and 5 each pair of corresponding histograms demonstrated a close similarity of orientation trends. These areas were photographically covered by imagery taken in the fall of the year when foliage was at a minimum. All three fracture trace and lineament recognition elements (topographic-erosional, soil tonal, vegetational) were utilized in the interpretative phase maximizing accuracy and reliability of analysis. Bedrock exposures were numerous enabling the collection of sufficient comparative field data.

Areas 2 and 3 were covered by imagery exhibiting a dense vegetational canopy. Interpretation of photogeologic linears was restricted to vegetational alignments and undoubtably a number of fracture traces and lineaments that would otherwise be apparent went unrecorded as they were obscured by foliage. The photogeologic data collected in these areas may thus be biased towards a particular orientation as most vegetationally interpreted linears trended north-south. Fewer bedrock exposures and correspondingly fewer ground-observed fracture orientations contributed to a less than complete picture of fracture trends in these areas.

The lack of pronounced correlation between histograms of area 4 was probably the result of an insufficient amount of comparative field data. Aerial photographs indicated extensive bedrock exposures in strip-mines but when these sites were visited they had been reclaimed and the exposures buried. Field data acquisition sites were restricted to poor exposures in isolated road cuts.

II. DIRECT COMPARISION OF PHOTOGEOLOGIC LINEAR DIRECTIONS TO GROUND-OBSERVED FRACTURE ORIENTATIONS

At each of the specific localities cited in Chapter IV joint sets were observed that demonstrated a significant parallelism with the trend of the photogeologic linear(s) that intersected the exposure. Comparison of photogeologic linears and bedrock fractures revealed similarities in orientation that deviated no more than four degrees at any of the sites. In some instances the correlative fracture set also exhibited the most pronounced structural development. Where all ground-observed fractures appeared equally developed, the set with the correlative orientation was assumed responsible for the surficial expression of the photogeologic linear.

Sites 14 and 15 were intersected by the same photogeologic linear that trended N.72°E. The two locations were characterized by fracture sets trending N.71°E. and N.70°E. respectively. It is significant to note that the parallelism of corresponding bedrock fracture and photogeologic linear orientations was maintained over a distance of approximately 2300' (701m).

III. ORIGIN OF JOINTS

Conclusions regarding the origin or origins of joints in the study must be regarded as tentative. The area of investigation has been restricted to the eastern portion of the Wartburg Basin. For this reason, only local conditions of fracture propagation may be reflected. The possibility of regional variations over the rest of the basin should be considered.

The Wartburg Basin is a section of the Cumberland Plateau characterized by horizontally bedded rocks that are essentially undisturbed. Wilson and Stearns (1958) state: "The gentle east dip off the flank of the Cincinnati Arch . . . is the only structure affecting the undisturbed area. . . ." Any discussion of possible joint origins must take into account the following observations:

1. all joints observed in the research area are essentially vertical,
2. the east flank of the Cincinnati Arch represents a surface of extension that trends southeast.

Several theories have been postulated for the origin of joints in tectonically similar areas elsewhere on the Appalachian Plateaus. Most joints of regional extent are probably due to tensile or shearing stresses.

If the joints in the study area are classified as shear fractures, the following situation exists: the axis of least principle stress (σ_3) would be oriented parallel to the southeast trend of the flank of the Cincinnati Arch. Price (1966) notes that the line of intersection of conjugate shear planes lies parallel to the axis of intermediate principle stress (σ_2). Since all observed joints are essentially vertical, the orientation of σ_2 would also be vertical. The maximum principle stress direction (σ_1) would be oriented parallel to the northeast strike of the Cincinnati Arch. Joints in the study area are generally planar and observed to cut successive lithologies. This is consistant with the observations of Parker (1942) regarding shear joints. However, it is difficult to explain the general absence of "plumose" surface structures, slickensides, and offsets that are indicative of initial shear conditions.

Nickelsen and Hough (1967) attribute the origin of joints on the Appalachian Plateau of Pennsylvania to extension normal to the direction of least principle stress (σ_3). If the joints in the study area are classified as tensile structures normal to the axis of extension an additional problem arises. Changing or multiple stress fields would be required to account for different joint set orientations.

Residual tectonic stresses and unloading of overburden by erosion have been suggested as mechanisms of joint propagation whose roles have not yet been fully explained.

Data so far are insufficient to determine the stress field orientations that produced the jointing.

IV. SIGNIFICANCE OF FRACTURE TRACES AND LINEAMENTS

Photogeologic fracture traces and lineaments have been associated with faults, joints, and areas of increased fracture density. Lineaments often represent the surficial expression of major shatter zones that extend several kilometers into the subsurface. These zones can serve as conduits from hydrocarbon source rocks to reservoir rocks as well as from reservoir rocks to the surface. In some instances, the zones of fracture concentration are responsible for the creation of the reservoir or increased permeability in existing reservoirs. Fracture traces and lineaments may thus be indicative of geologic structures that create, enhance, or destroy petroleum reservoirs.

CHAPTER VI

CONCLUSIONS

Data collected during this investigation indicate that photogeologic fracture traces and lineaments are useful for locating major bedrock structures and areas of increased fracture density. Strike orientations of photogeologic linears and bedrock fractures were compared regionally by histograms and on an individual basis in the field. The degree of successful correlation varied between the two methods.

Gross similarities of strike maxima existed between corresponding photogeologic linear and bedrock fracture histograms. Strike maxima of fracture trace and lineament histograms not present on joint histograms, may indicate bedrock fractures not sufficiently developed to be expressed on the surface. Where strike maxima do not coincide, the lack of correlation may be the result of inadequate field data. Suitability of imagery was revealed to be a critical factor in terms of interpretation and analysis.

At several sites of known fracture trace or lineament intersection, the orientations of bedrock fractures and photogeologic linears were compared. Direct comparison revealed a significant parallelism between the strike directions of photogeologic linears and bedrock joints.

In the area of study in the Wartburg Basin, photogeologic mapping can be used to interpret the presence of bedrock structures obscured by soil and vegetation. Results should be verified by additional field studies.

LIST OF REFERENCES

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Allum, J. A. E., 1966, Photogeology and Regional Mapping: Pergamon Press, New York, 107 p.

Alpay, O. A., 1973, Application of Aerial Photographic Interpretation to the Study of Reservoir Natural Fracture Systems: J. Petrol. Technol., v. 25, no. 1, p. 37-45.

________, 1967, International Tectonic Dictionary: American Association of Petroleum Geologists, Tulsa, 196 p.

________, 1976, Manual of Photographic Interpretation (4th ed.): American Society of Photogrammetry, Falls Church, Va.

________, 1976, The Economic Impact of Back to Contour Reclamation of the Surface Coal Mines in Appalachia: The TVA Massengale Mountain Project Final Report, Appalachian Resources Project, Knoxville, 230 p.

Avery, T. E., 1962, Interpretation of Aerial Photographs: Burgess Publishing Company, Minneapolis, 192 p.

Barlow, J. A., 1969, Stratigraphy and Paleobotany of the Youngest Pennsylvanian Strata in the Caryville, Tennessee Area: Unpublished doctorate dissertation, The University of Tennessee, Knoxville.

Billings, M. P., 1962, Structural Geology: Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 606 p.

Blanchet, P. D., 1957, Development of Fracture Analysis as Exploration Method: Bull. AAPG, v. 41, no. 8, p. 1748-1759.

de Sitter, L. U., 1964, Structural Geology: McGraw-Hill Book Company, New York, 551 p.

Halbouty, M. T., 1976, Application of LANDSAT Imagery to Petroleum and Mineral Exploration: Bull. AAPG, v. 60, no. 5, p. 745-793.

Heck, E. T., 1955, Fractures and Joints: Producers Monthly, v. 19, no. 2, p. 20-23.

Hobbs, W. H., 1911, Repeating Patterns in the Relief and in the Structure of the Land: Geol. Soc. of Amer. Bull., v. 22, p. 123-176.

Hodgson, R. A., 1961, Classification of Structures on Joint Surfaces: Amer. Jour. of Sci., v. 259, p. 493-502.

Holz, R. K. (editor), 1973, The Surveillant Science—Remote Sensing of the Environment: Houghton Mifflin Company, Boston, 309 p.

Kaiser, E. P., 1950, Structural Significance of Lineaments (abs.), Geol. Soc. of Amer. Bull., v. 61, no. 12, p. 1475-1476.

Komar, C. A., Overbey, W. K., Jr., Rough, R. L., and Lambert, W. G., 1971, Factors That Predict Fracture Orientation in a Gas Storage Reservoir: J. Petrol. Technol., v. 23, no. 5, p. 546-550.

Lahee, F. H., 1961, Field Geology: McGraw-Hill Book Company, New York, 926 p.

Lattman, L. H., 1958, Technique of Mapping Geologic Fracture Traces and Lineaments on Aerial Photographs: Photogram. Eng., v. 24, no. 4, p. 568-576.

Lattman, L. H., and Nickelsen, R. P., 1958, Photogeologic Fracture-Trace Mapping in Appalachian Plateau: Bull. AAPG, v. 42, no. 9, p. 2238-2245.

Lattman, L. H., and Ray, R. G., 1965, Aerial Photographs in Field Geology: Holt, Rinehart, and Winston, New York, 221 p.

Luther, E. T., 1959, The Coal Reserves of Tennessee: Tenn. Div. of Geol. Bull. 63, 294 p.

McCallum, M. E., 1958, The Geology of the Western Half of the Quadrangle, Campbell County, Tennessee: Unpublished Master's Thesis, The University of Tennessee, Knoxville.

Miller, V. C., and Miller, C. F., 1961, Photogeology: McGraw-Hill, New York, 248 p.

Nickelsen, R. P., and Hough, V. D., 1967, Jointing in the Appalachian Plateau of Pennsylvania: Geol. Soc. of Amer. Bull., v. 78, pt. 1, p. 609-629.

________, 1967, Fracture Orientation Study to Aid Petroleum Production: Oil and Gas Jour., v. 65, no. 23, p. 141-142.

Overbey, W. K., Jr., Komar, C. A., and Pasini, J., III, 1973, Predicting Probable Roof Fall Areas in Advance of Mining by Geological Analysis: Bureau of Mines Health and Safety Research Program, Technical Progress Report 70, Morgantown Energy Center, W. Va. 17 p.

Overbey, W. K., Jr., and Rough, R. L., 1968, Surface Studies Predict Orientation of Induced Formation Fractures: Producers Monthly, v. 32, no. 6, p. 16-19.

Overbey, W. K., Jr., and Rough, R. L., 1968, Surface-Joint Patterns Predict Well-Bore Fracture Orientation: Oil and Gas Jour., v. 66, no. 9, p. 84-86.

Overbey, W. K., Jr., and Rough, R. L., 1971, Prediction of Oil-and-Gas-Bearing Fractures from Surface Structural Features: Bureau of Mines RI 7500, 14 p.

Parker, J. M., III, 1942, Regional Systematic Jointing in Slightly Deformed Sedimentary Rocks: Geol. Soc. of Amer. Bull., v. 53, p. 381-408.

Price, N. J., 1966, Fault and Joint Development in Brittle and Semi-Brittle Rock: Pergamon Press, New York, 176 p.

Ray, R. G., 1960, Aerial Photographs in Geologic Interpretation and Mapping: U.S. Geol. Surv. Prof. Paper 373, 230 p.

Roberts, J. C., 1961, Feather-Fracture and the Mechanics of Rock-Jointing: Amer. Jour. of Sci., v. 259, p. 481-492.

Sabins, F. F., Jr., 1978, Remote Sensing—Principles and Interpretation: W. H. Freeman and Company, San Francisco, 425 p.

Spencer, E. W., 1969, Introduction to the Structure of the Earth: McGraw-Hill Book Company, New York, 597 p.

Spoljaric, N., Jordan, R. R., and Sheridan, R. E., 1976, Inference of Tectonic Evolution from LANDSAT-1 Imagery: Photogram. Eng. and Rem. Sens., v. 42, no. 8, p. 1069-1082.

Welby, C. W., 1976, LANDSAT-1 Imagery for Geologic Evaluation: Photogram. Eng. and Rem. Sens., v. 42, no. 11, p. 1411-1419.

Wilson, C. W., Jewell, J. W., and Luther, E. T., 1956, Pennsylvanian Geology of the Cumberland Plateau: Tenn. Div. of Geol. Folio, 21 p.

Wilson, C. W., and Stearns, R. G., 1958, Structure of the Cumberland Plateau, Tennessee: Geol. Soc. of Amer. Bull., v. 69, p. 1283-1296.

APPENDIXES

APPENDIX A

HISTOGRAMS OF PHOTOGEOLOGIC LINEAR FEATURE ORIENTATIONS

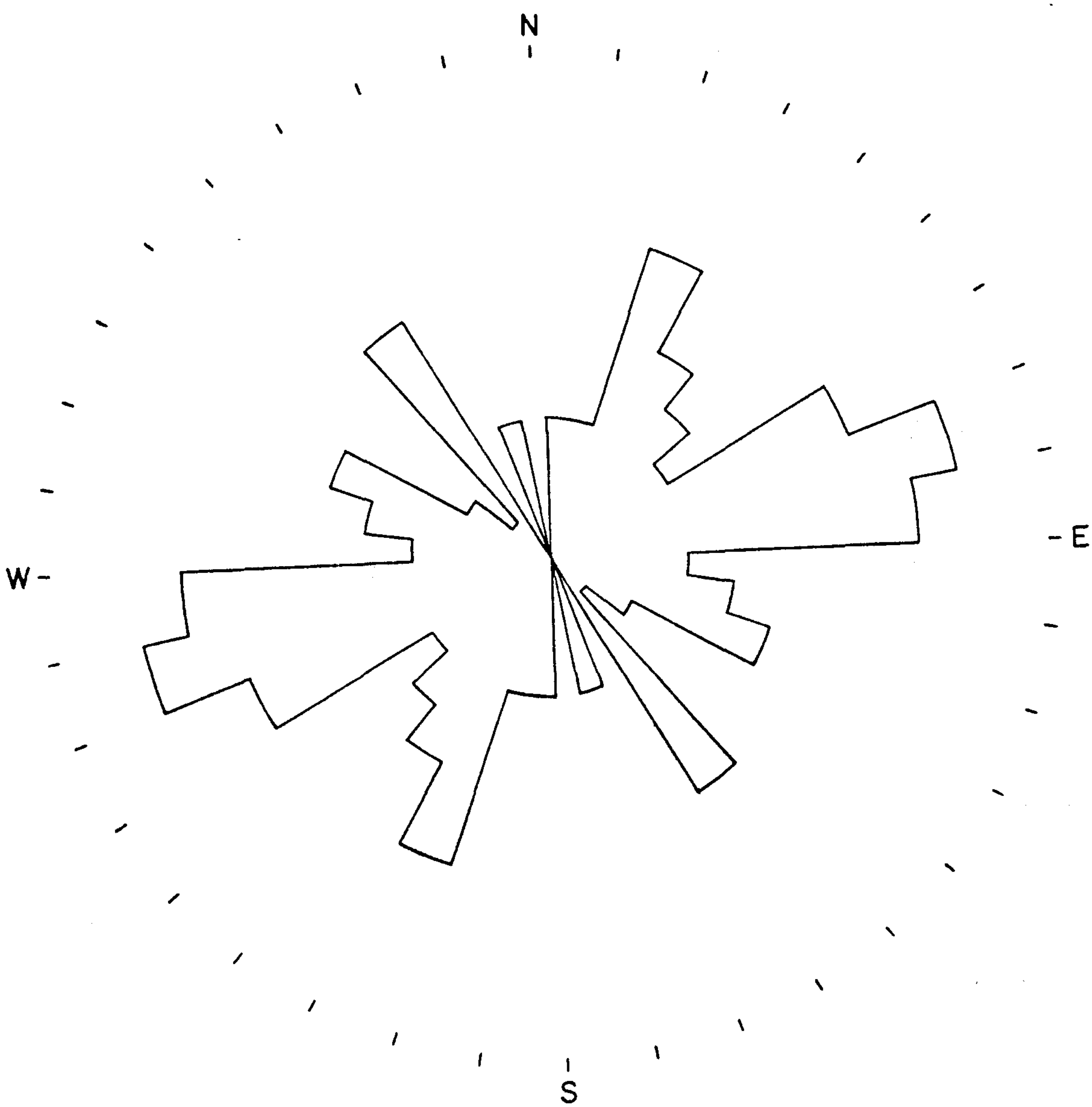

Figure A1. Histogram of photogeologic fracture traces and lineaments mapped within geographic subdivision 1, based upon 73 observations.

A preferred orientation exists in the northeast quadrant. The fracture trace-lineament maximum is N.70°-80°E. Secondary, tertiary, and quaternary maxima occur at N.20°-30°E., N.30°-40°W., and N.60°-70°W. respectively.

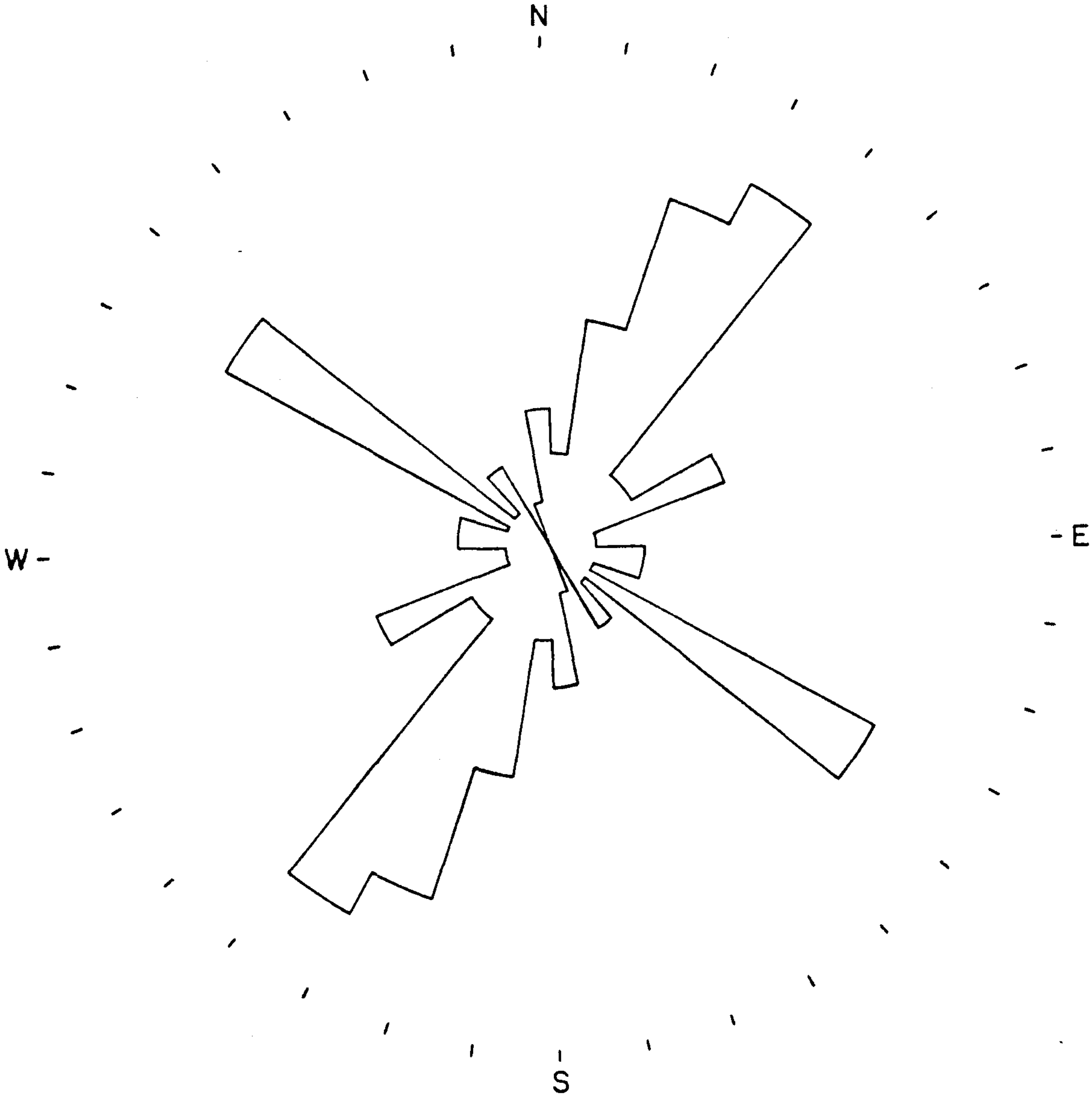

Figure A2. Histogram of photogeologic fracture traces and lineaments mapped within geographic subdivision 2, based upon 54 observations.

A preferred orientation exists in the northeast quadrant. The fracture trace-lineament maximum is N.30°-40°E. Secondary and tertiary maxima occur at N.50°-60°W. and N.60°-70°E. respectively.

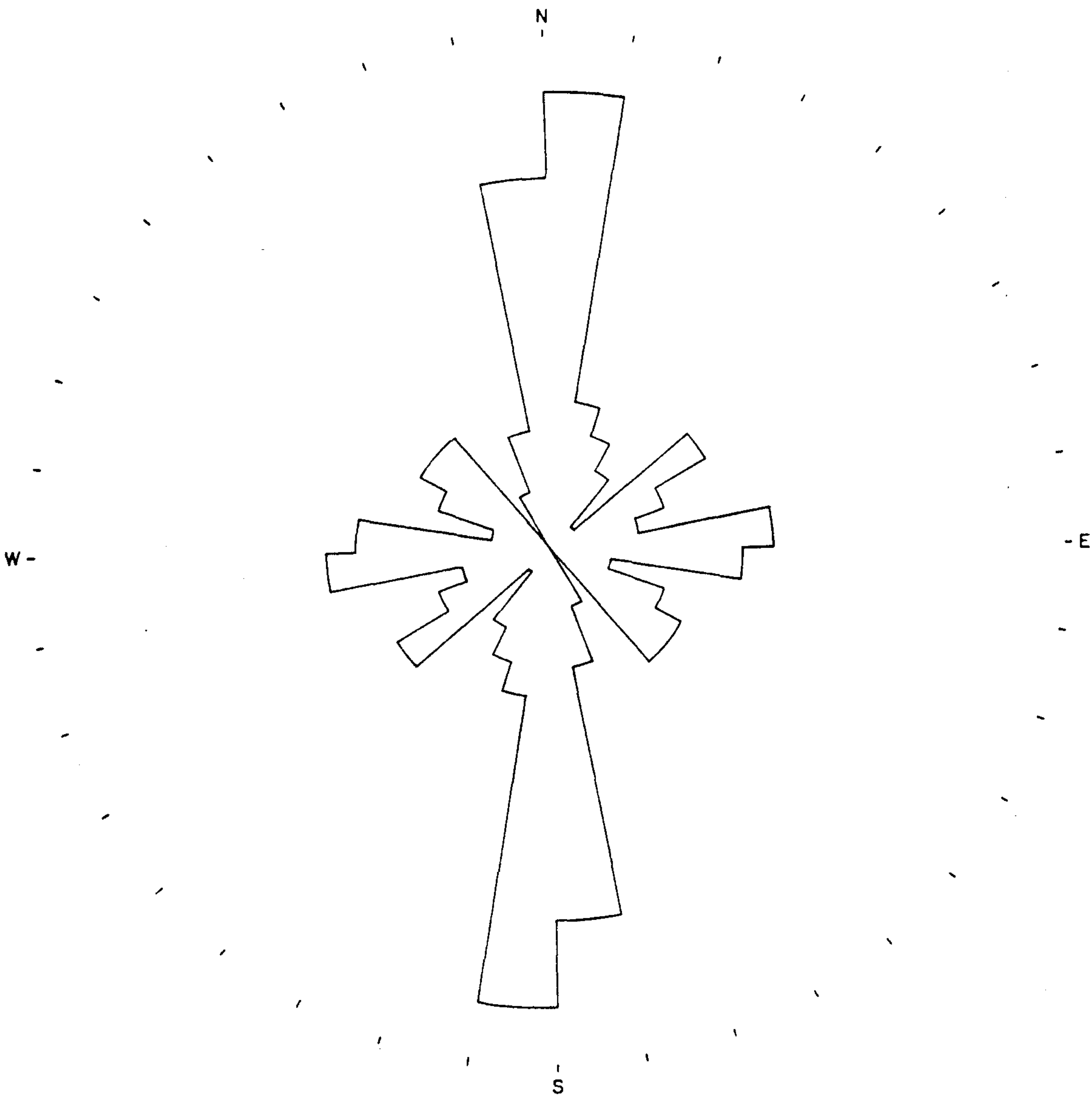

Figure A3. Histogram of photogeologic fracture traces and lineaments mapped within geographic subdivision 3, based upon 90 observations.

A preferred orientation exists in the northeast quadrant. The fracture trace-lineament maximum is at N.0°-10°W. Secondary, tertiary, and quaternary maxima occur at N.80°-90°E., N.40°-60°W., and N.50°-60°E. respectively.

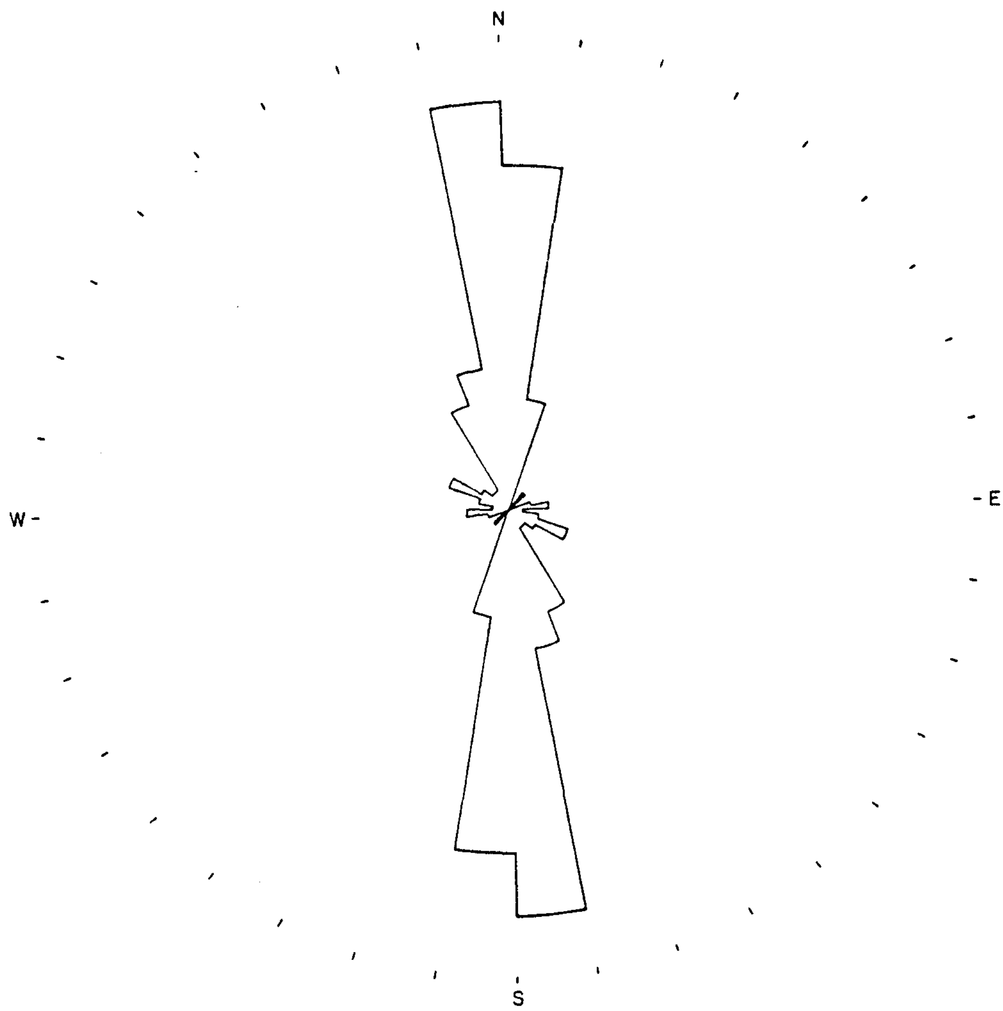

Figure A4. Histogram of photogeologic fracture traces and lineaments mapped within geographic subdivision 4, based upon 86 observations.

A preferred orientation exists in the northeast quadrant. The fracture trace-lineament maximum is N.0°-10°W. A very minor secondary maximum occurs at N.60°-70°W.

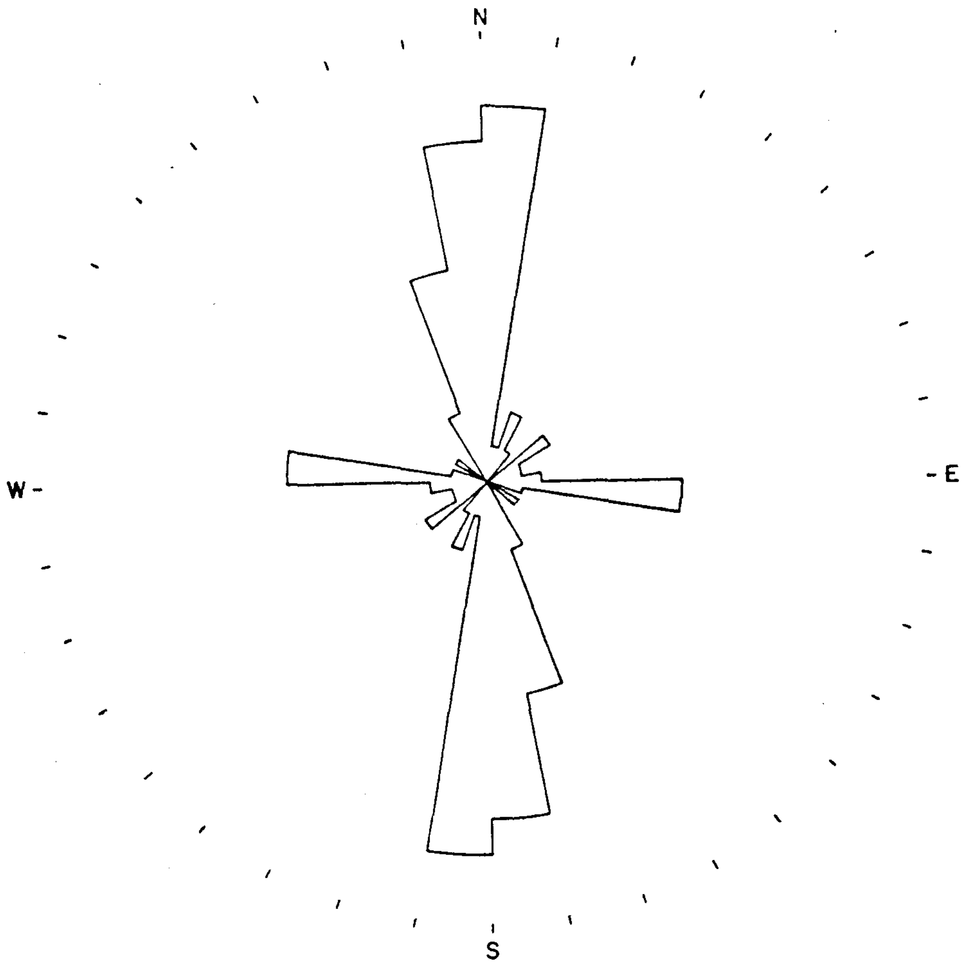

Figure A5. Histogram of photogeologic fracture traces and lineaments mapped within geographic subdivision 5, based upon 45 observations.

A preferred orientation exists in the northeast quadrant. The fracture trace-lineament maximum is N.0°-10°E. A secondary maximum occurs at N.80°-90°W.

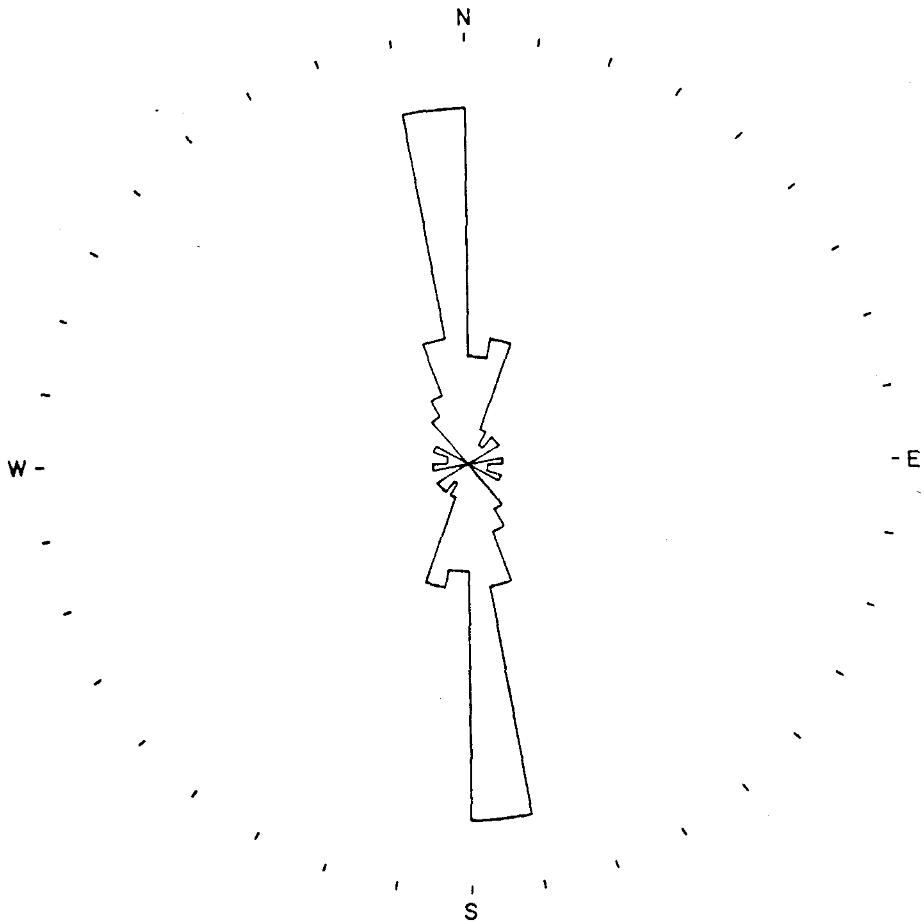

Figure A6. Histogram of photogeologic fracture traces and lineaments mapped within geographic subdivision 6, based upon 60 observations.

A preferred orientation exists in the northwest quadrant. The fracture trace-lineament maximum is N.0°-10°W. A secondary maximum occurs at N.10°-20°E.

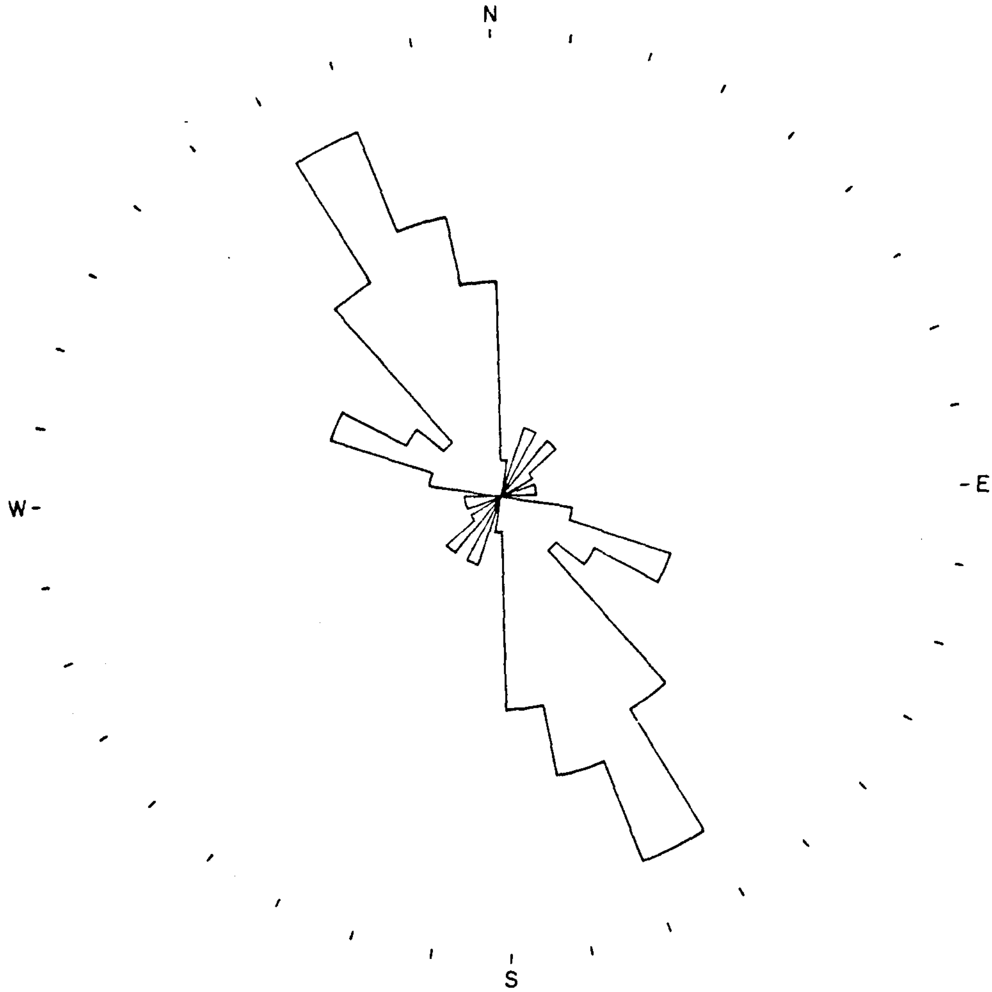

Figure A7. Histogram of photogeologic fracture traces and lineaments mapped within geographic subdivision 7, based upon 52 observations.

A preferred orientation exists in the northwest quadrant. The fracture trace-lineament maximum is N.20°-30°W. A secondary maximum occurs at N.60°-70°W.

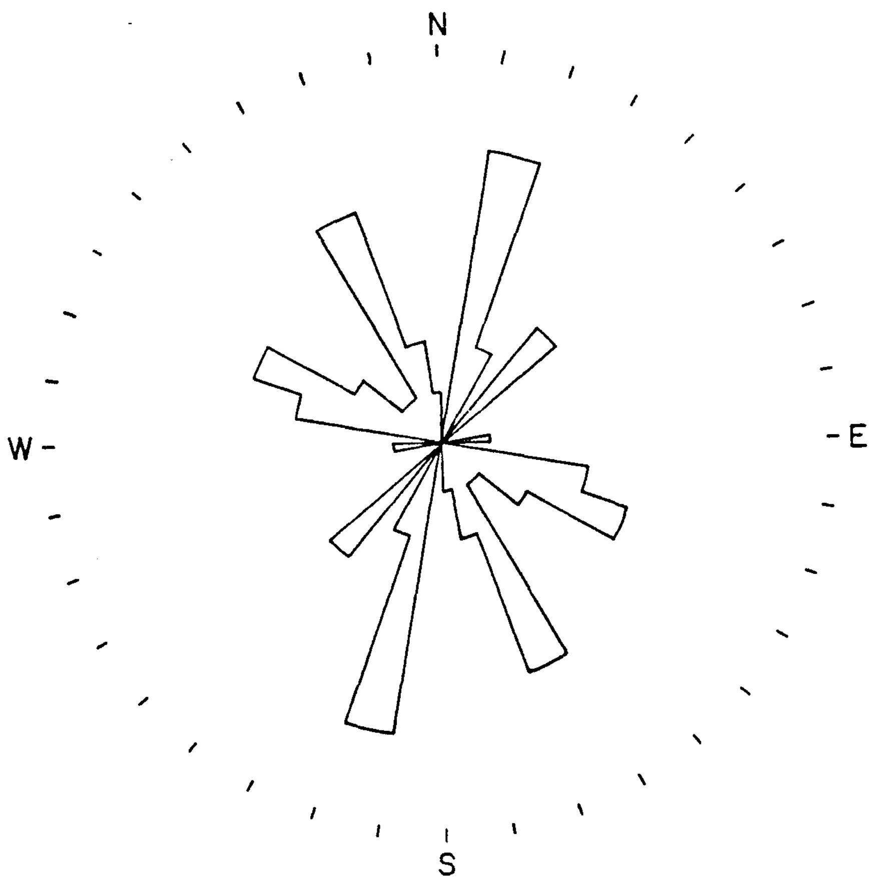

Figure A8. Histogram of photogeologic fracture traces and lineaments mapped within geographic subdivision 8, based upon 31 observations.

The fracture trace-lineament maximum is at N.10°-20°E. Secondary, tertiary, and quaternary maxima occur at N.20°-30°W., N.60°-70°W., and N.40°-50°E. respectively.

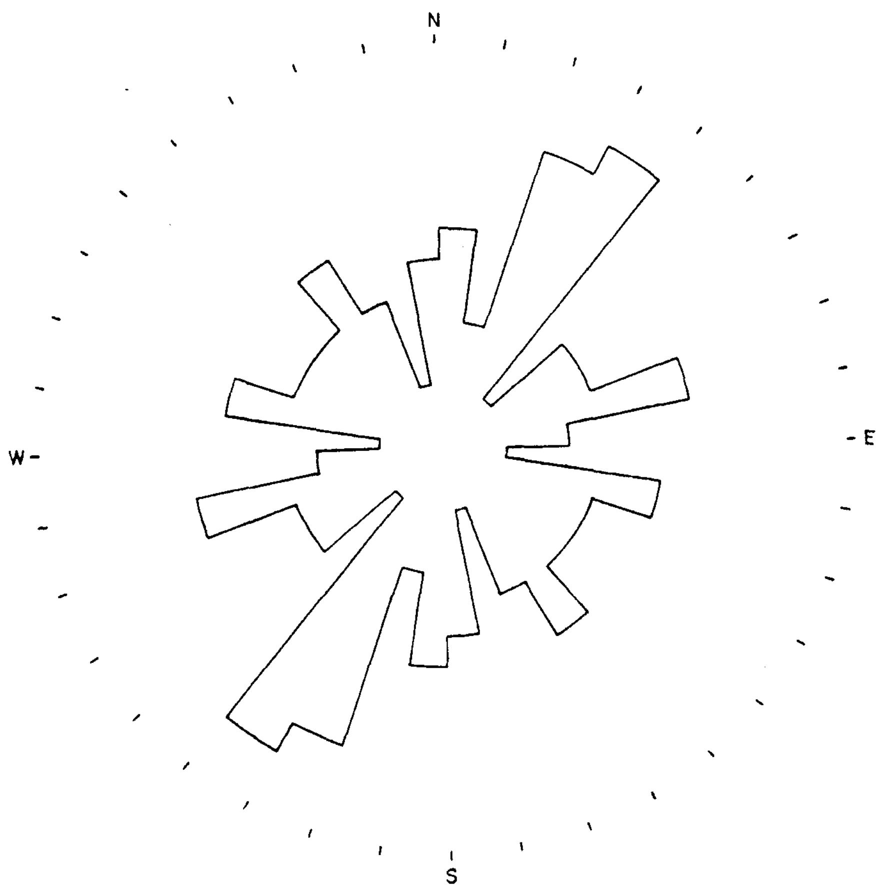

Figure A9. Histogram of photogeologic fracture traces and lineaments mapped within geographic subdivision 9, based upon 100 observations.

A preferred orientation exists in the northeast quadrant. The fracture trace-lineament maximum is at N.30°-40°E. Secondary and tertiary maxima occur at N.70°-80°E. and N.0°-10°E., N.30°-40°W., and N.70°-80°W. respectively.

APPENDIX B

HISTOGRAMS OF BEDROCK FRACTURE ORIENTATIONS

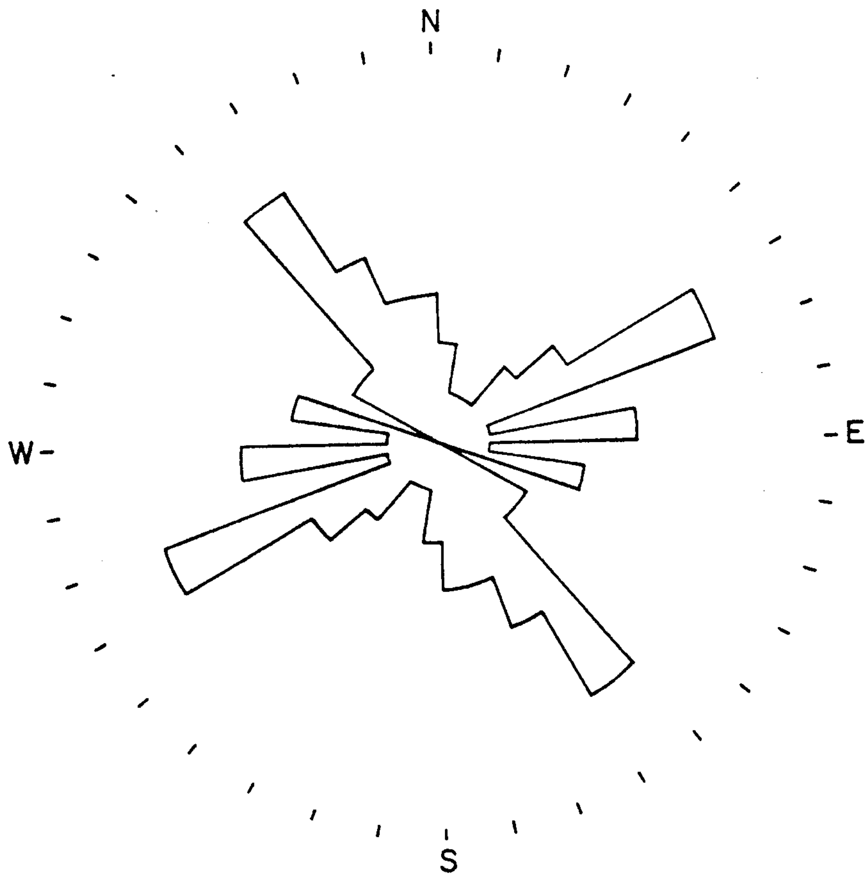

Figure B1. Histogram of bedrock fracture orientations based upon 45 observations from sites 1, 2, 3, and 8; area 1.

The bedrock fracture maxima are at N.30°-40°W. and N.60°-70°E. A secondary maximum occurs at N.80°-90°E.

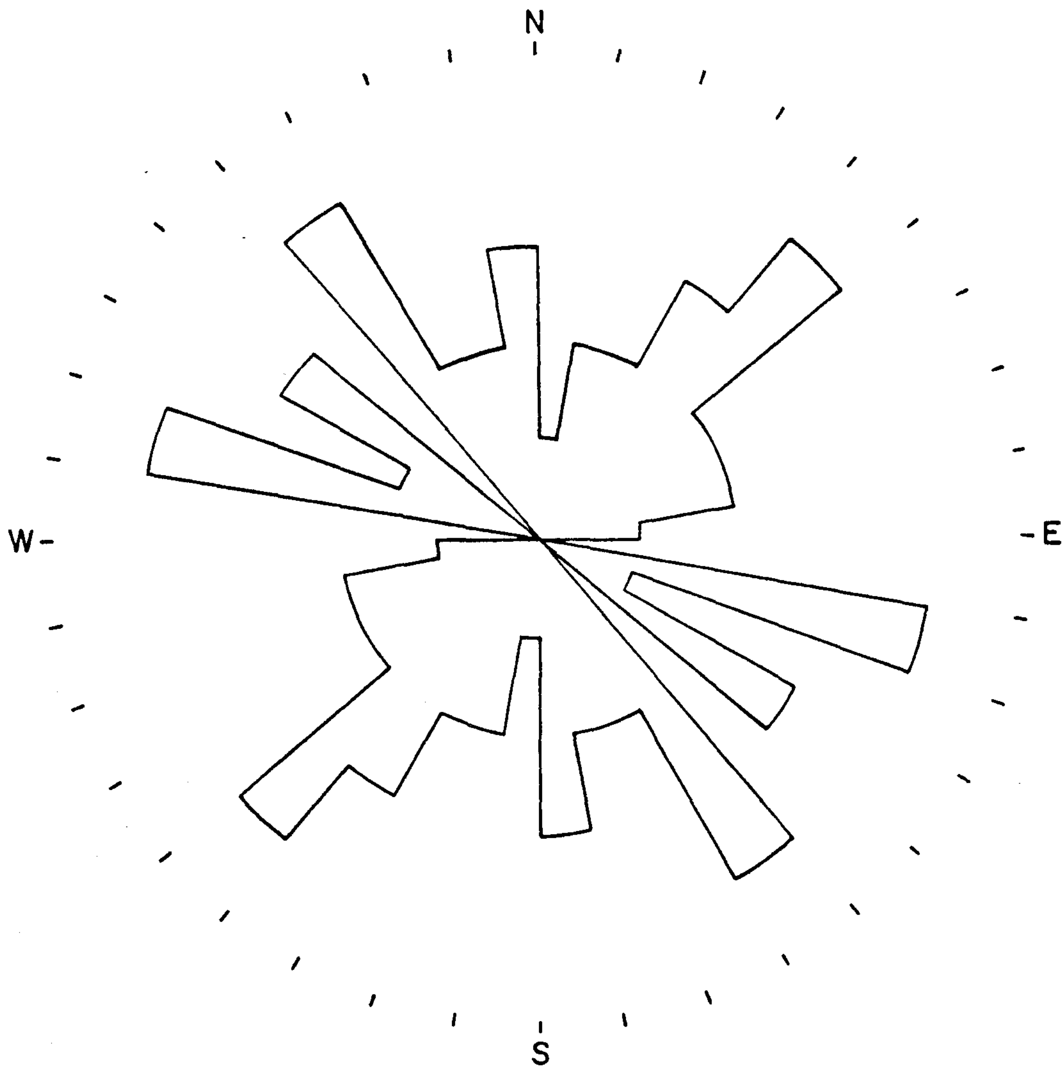

Figure B2. Histogram of bedrock fracture orientations based upon 38 observations from sites 4, 5, and 9; area 2.

The primary bedrock fracture maxima are at N.30°-40°W., N.70°-80°W., and N.40°-50°E. Secondary maxima occur at N.0°-10°W. and N.50°-60°W.

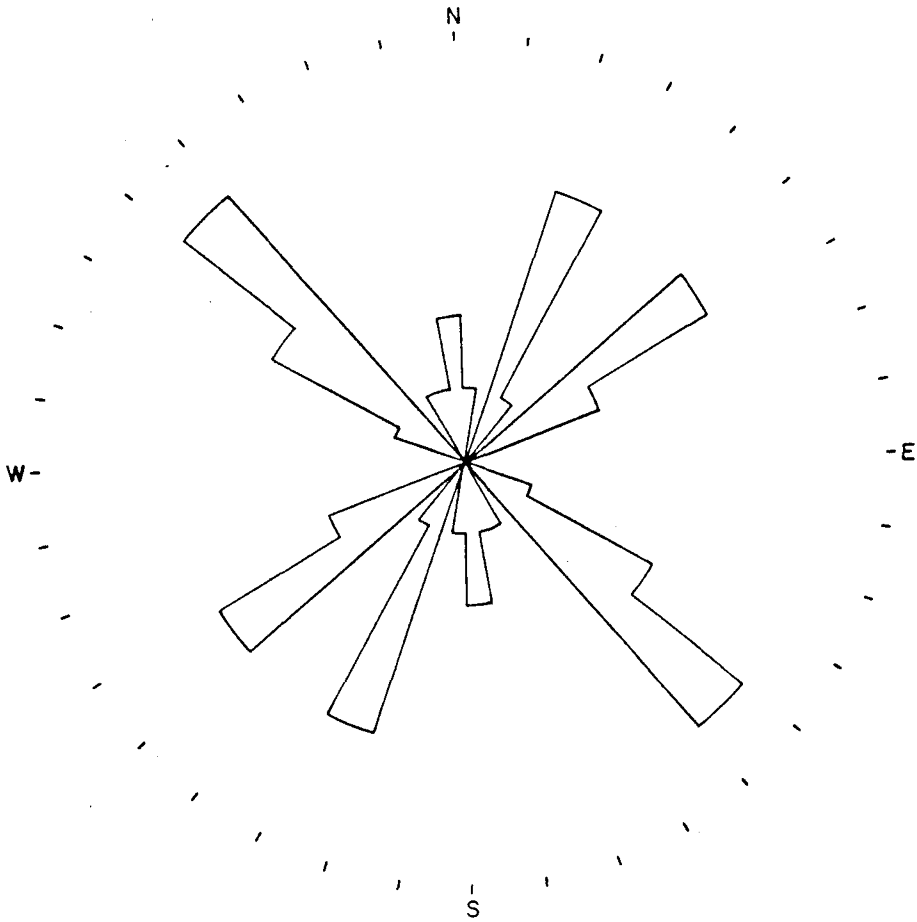

Figure B3. Histogram of bedrock fracture orientations based upon 26 observations from sites 6, 7, and 13; area 3.

A preferred orientation exists in the northwest quadrant. The bedrock fracture maximum is at N.40°-50°W. Secondary maxima occur at N.20°-30°E. and N.50°-60°E.

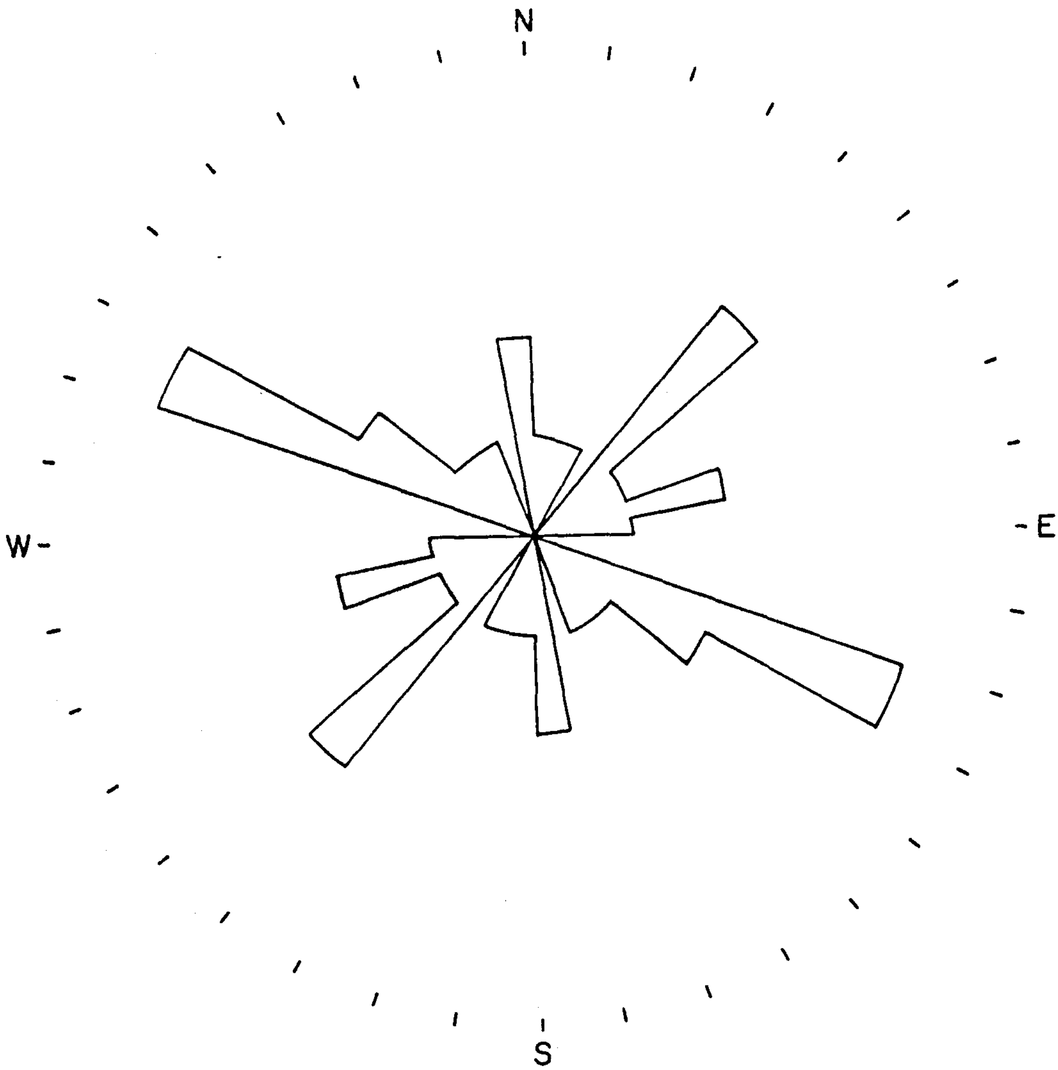

Figure B4. Histogram of bedrock fracture orientations based upon 22 observations from sites 16 and 17; area 4.

A preferred orientation exists in the northwest quadrant. The bedrock fracture maximum is at N.60°-70°W. Secondary and tertiary maxima occur at N.40°-50°E. and at N.0°-10°W. and N.70°-80°E. respectively.

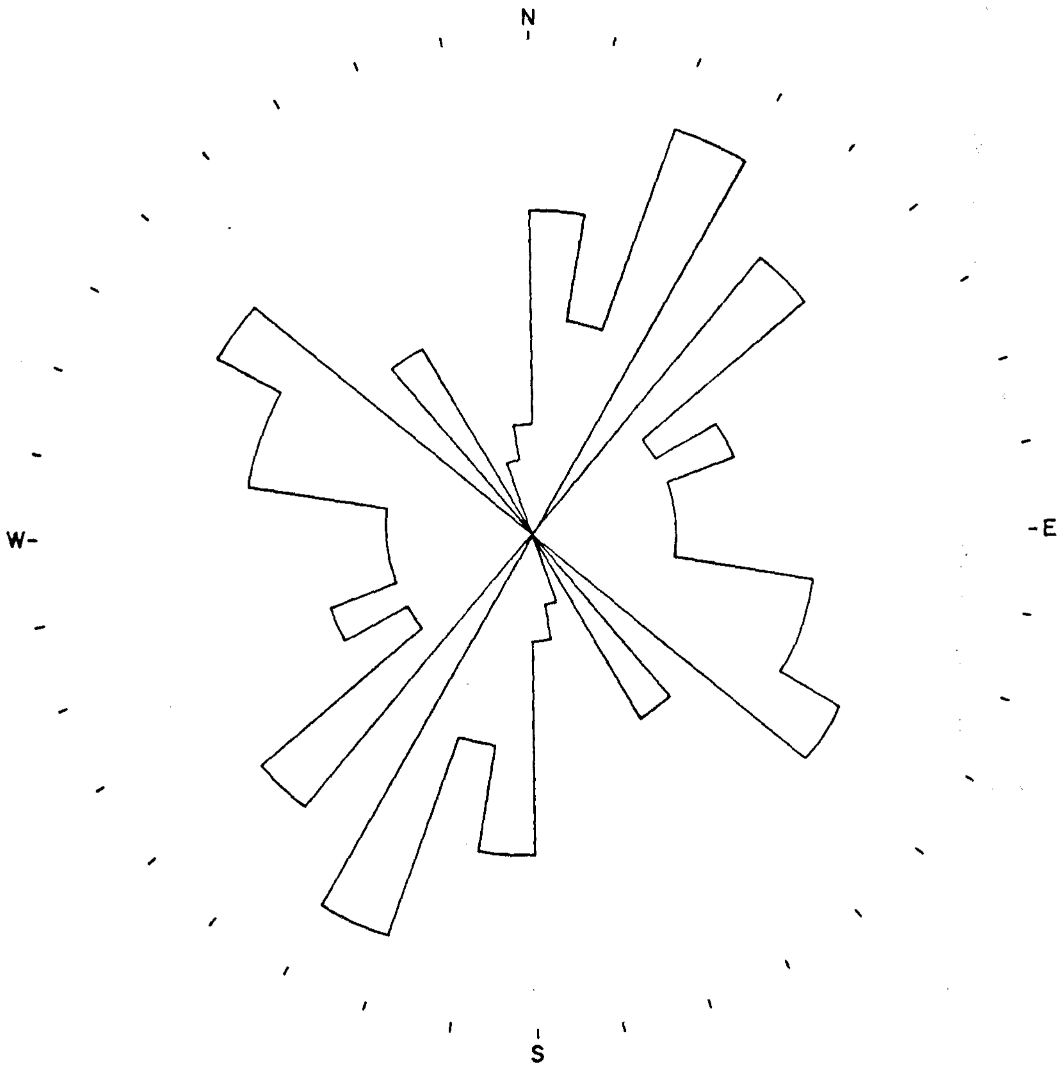

Figure B5. Histogram of bedrock fracture orientations based upon 48 observations from sites 10, 11, 12, 14, and 15; area 5.

A preferred orientation exists in the northeast quadrant. The bedrock fracture maximum is at N.20°-30°E. Secondary maxima occur at N.0°-10°E., N.40°-50°E., and N.50°-60°W.

VITA

Mark L. Slusarski was born in Aberdeen, Maryland on March 16, 1950. He attended Aberdeen High School, graduating in 1968.

He completed four semesters of work at Harford Community College in Bel Air, Maryland before transferring to Virginia Polytechnic Institute and State University in Blacksburg, Virginia in the fall of 1970. He received his Associate of Arts degree from Harford Community College and his Bachelor of Science degree from Virginia Polytechnic Institute in March, 1973.

Before entering The University of Tennessee for graduate work in April of 1974, Mr. Slusarski worked for Associated Engineers and Surveyors, Inc., Bel Air, Maryland. During the summers of 1974, 1975, and 1976 he was employed as an exploration geologist by the mineral division of Continental Oil Company, Athens, Georgia. He is a member of the American Society of Photogrammetry, the American Association of Petroleum Geologists, and Sigma Gamma Epsilon. Mr. Slusarski will be employed with the Natural Resources Group, Exploration Staff, Phillips Petroleum Company after graduation.

In July, 1976, he was married to Mary Catherine Zacchi of Clinton, Tennessee.