FRACTURE PATTERNS AND FLOW ORIENTATION IN THE CARLTON RHYOLITE, WICHITA MOUNTAINS AREA, SOUTHWEST OKLAHOMA

By

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May, 1982

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
July, 1985

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ACKNOWLEDGMENTS

The author wishes to thank all of the people who helped in various capacities during the course of this project. Dr. Nowell Donovan gave encouragement and technical advice. Dr. Gary Stewart and Dr. Arthur Hounslow gave time to be other members of my committee. My mother and father financed the project. To all others who helped, thank you.

The author owes a very special debt of thanks to the Lord, who gave me His grace to complete the project, especially when I felt I could not continue.

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CHAPTER I

INTRODUCTION

Purpose of Study

This study is a geometrical analysis of the fracture pattern found in the Cambrian Carlton Rhyolite of the Blue Creek Canyon area in the Wichita Mountains. The principle aim of the study is to establish the cause of the fracture pattern. Three fracture pattern relationships examined are:

1. relationship to the late Paleozoic (Pennsylvanian-Permian) Blue Creek Canyon Fault,
2. relationship to cooling joints in the rhyolite, and
3. relationship to earlier Paleozoic pre-faulting tectonics in the region.

The fracture pattern is also compared with fracture patterns found in the Cambrian granites of the Wichita Mountains.

Region of Study

Geographic Aspects

The areas of study are located in the Wichita Mountains of Southwest Oklahoma (Figure 1). The Blue Creek Canyon area is located in sections 1, 2, 11, 12, 13, 14, T4N R13W, and sections 7 and 18, T4N R12W in Comanche and Caddo Counties. During the course of the study,

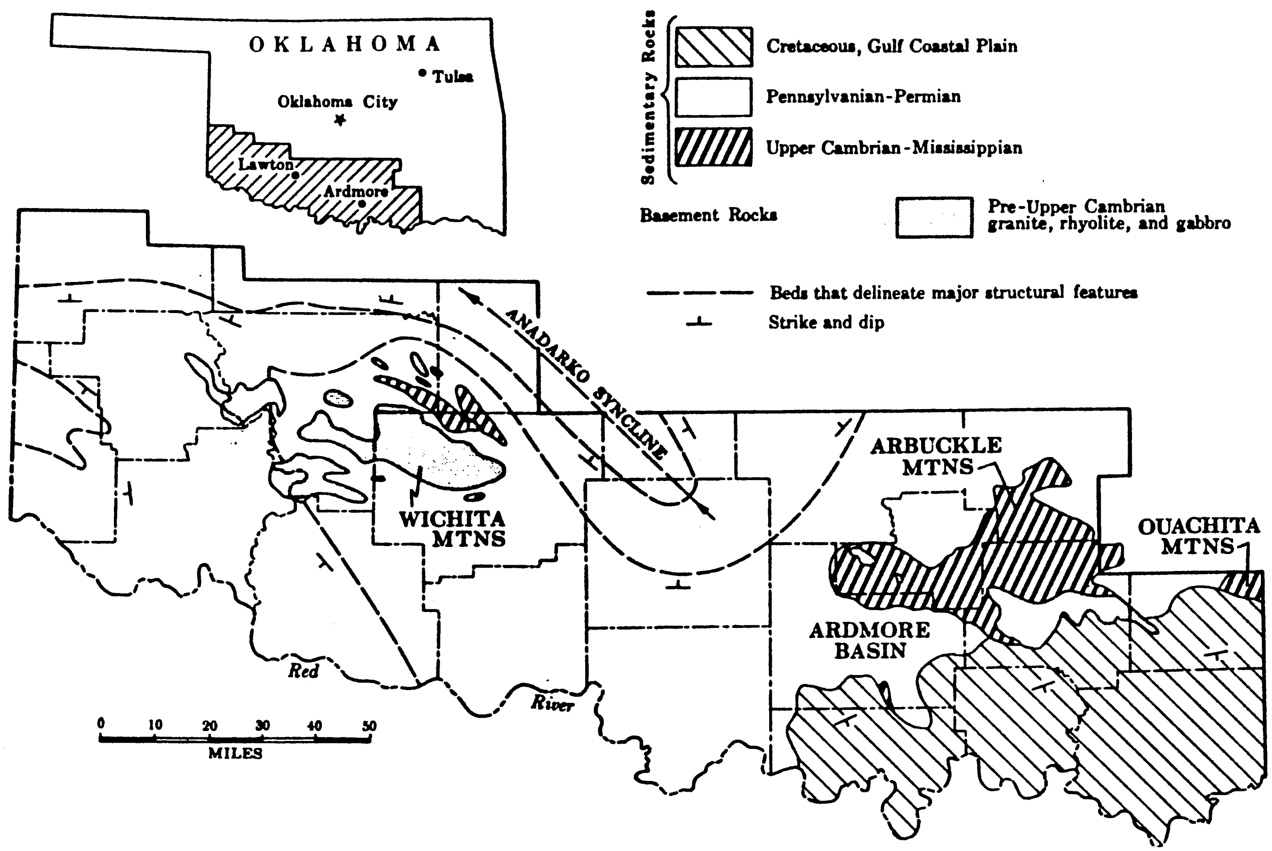

Figure 1. Index Map of Southern Oklahoma (After Ham et al., 1964)

outcrops at Bally Mountain (sections 21, 27, 28, 34, T6N R14W) and Zodletone Mountain (sections 16, 17, T6N R14W) were also examined.

General Geologic Aspects

The Wichita Mountains are a group of pre-Cambrian to Cambrian igneous bodies that form low hills in Southwest Oklahoma. The present topographic profile is a recently exhumed Permian land surface (Gilbert, 1982; Figure 2). Together with the igneous rocks of the Arbuckle Mountains, the igneous rocks of the Wichitas comprise the only useful exposures of basement rock in the southern mid-continent (Gilbert, 1982). In their tectonic setting, the Wichitas and the Arbuckles form part of the Southern Oklahoma aulacogen, which is discussed in more detail in the following chapter.

Previous Work

Rhyolite is a fine-grained, aphanitic, volcanic rock consisting chiefly of alkali feldspar and quartz, with variable amounts of accessory minerals (Hatch et al., 1972). The first record of rhyolites and other igneous rocks in the Wichitas was provided in 1852, when Dr. George G. Shumard, physician for the first scientific expedition to the area, " . . . noted the presence of igneous rocks of the mountains and stratified sediments of the surrounding plains" (Taff, 1904, p. 51). Shumard observed that granites and porphyry (rhyolite) were widespread throughout the mountains, and in places were cut by "veins" of quartz and "greenstone" (diabase) (Taff, 1904).

In 1899, T. B. Comstock and W. F. Cummins made a reconnaissance of part of the Wichita Mountains, and classified the granite-porphyries

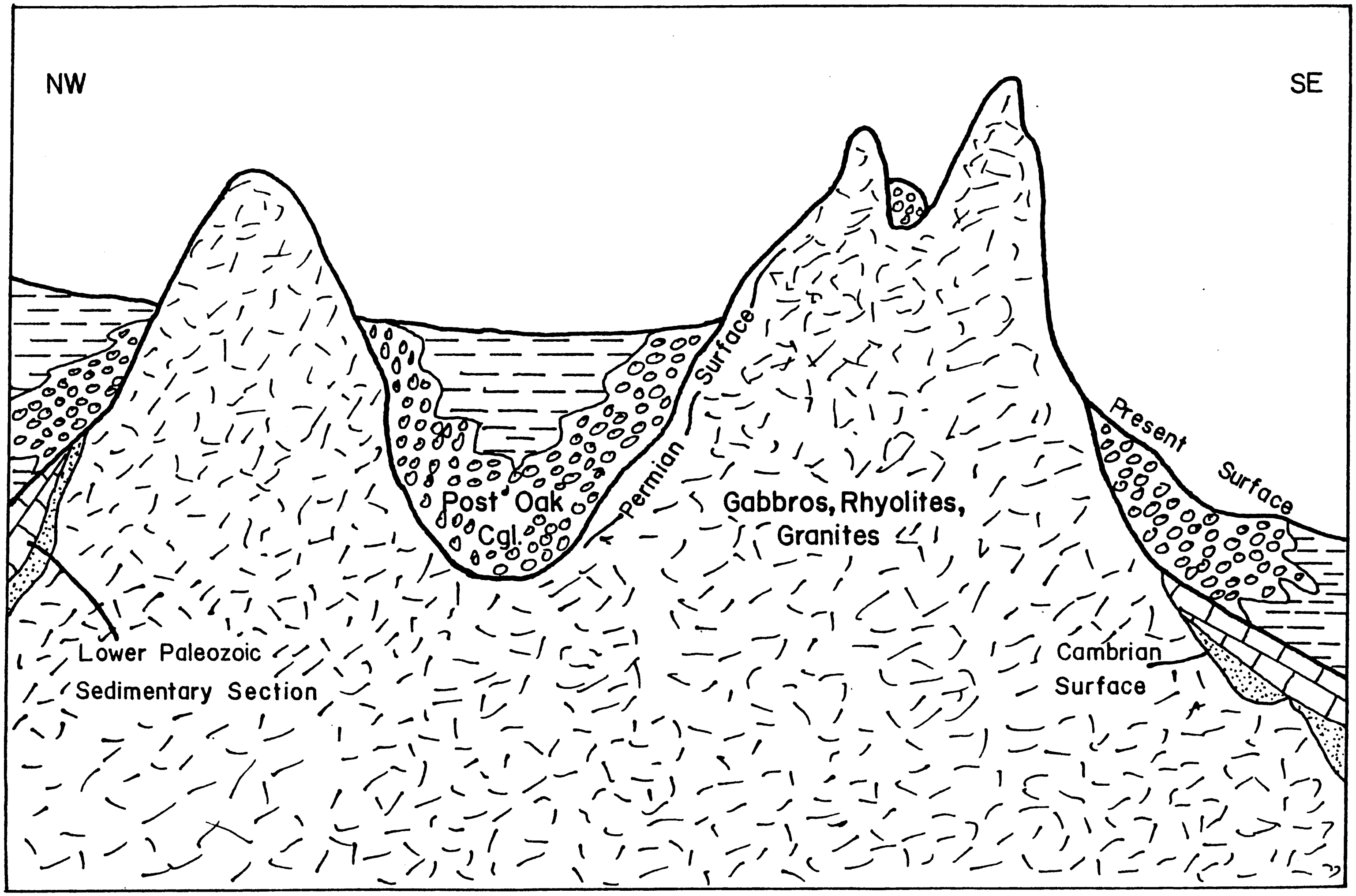

Figure 2. Diagrammatic Cross Section Across Wichita Mountains, Emphasizing Gradually Uncovered Permian Land Surface (Redrawn after Gilbert, 1982)

(rhyolites) of the "Carolton Mountains" as lavas representing stages of eruption; they also described the gabbros and diabases of the area (Taff, 1904). Also in 1899, H. F. Bain made a reconnaissance of the area, with emphasis on mineral resources. Bain described the different igneous rocks, and named the Carlton Rhyolite (present usage) as the "Carrollton Mountain Porphyry". Hoffman (1930) named the rhyolite the "Carolton Granophyre" (Ham et al., 1964). Tilton and others (1962) carried out isotopic age determinations and concluded that the Wichita Granites and Carlton Rhyolite are of Cambrian age (520 ± X M.Y.; Table I). Ham and others (1964) described the character of the Carlton Rhyolite in detail, using the Bally Mountain area as a type exposure. They stated that everywhere the Carlton Rhyolite outcropped, it consisted of rhyolite flows, tuffs, and agglomerates. They also discussed isotopic and stratigraphic ages, relative ages (with respect to the Wichita Granite Group), general petrology, and petrography. Hansen and Al-Shaieb (1980) made a detailed study of the petrology and geochemistry of the Carlton Rhyolite. It was determined that:

1. the majority of the Carlton Rhyolite was extruded as ash flows;
2. the Carlton Rhyolite was calc-alkaline in character;
3. the Carlton Rhyolite exhibited distinct trends in chemical composition, with Al_2O_3, Fe_2O_3, MgO, CaO, P_2O_5, TiO_2, Zn, and Cu all showing a decrease with increasing silica; Ba and Th, however, both showed increases with increasing silica;
4. K_2O, Na_2O, Mn, Li, Sr, and Pb, showed no relation to silica content;
5. trends in composition of the rhyolites studied could not be accounted for by a mechanism of differentiation to any significant degree;

TABLE I

ISOTOPIC AGES

Location/Rock	Mineral	$\frac{Rb^{87}}{Sr^{87}}$	$\frac{K^{40}}{Ar^{40}}$	$\frac{U^{238}}{Pb^{206}}$	$\frac{U^{235}}{Pb^{207}}$	$\frac{Pb^{207}}{Pb^{206}}$	$\frac{Th^{232}}{Pb^{208}}$
Lake Altus, OK/ Lugert Granite	Biotite	500 M.Y.	480 M.Y.				
Quanah Mt., OK/ Pegmatite	Zircon 1			520 M.Y.	525 M.Y.	550±30 M.Y.	505 M.Y.
	Zircon 2			515 M.Y.	520 M.Y.	550±20 M.Y.	495 M.Y.
Meers, OK/ Gabbro	Biotite	535±30 M.Y.	510 M.Y.				
Bally Mt., OK/ Carlton Rhyolite	Zircon			505 M.Y.	485 M.Y.	400±200 M.Y.	400±40 M.Y.

(Data from Tilton and others, 1962)

6. the rhyolites of the Ft. Sill area were the most acidic;
7. rhyolites and granites of the Wichita Province were not products of a single, uniform differentiation sequence; and
8. the Carlton Rhyolite had a relatively high average Th/U ratio, and a relatively low uranium content.

Aside from the work of Gilbert (1984), little has been published concerning fracture patterns in the Wichitas. Miser (1954) and Havens (1977) both published geologic maps (at scales of 1:500,000 and 1:250,000 respectively) on which they interpreted lineaments and joint patterns as faults. Gilbert (1984a) disagreed with Havens and Miser, stating that no evidence for major offset (100's of meters) can be found along most of the lineaments and joints mapped as faults. Indeed, he (Gilbert, 1984) cited evidence against offset along some of the lineaments and joints.

Related Studies: Joints-Procedures of Analysis

As a great number of joint/fracture studies have been made in other areas, a few selected, pertinent ones are now described. Balk (1937) described many types of joints that are found in igneous rocks (Table II). Price (1966) summarized the complete classification and surface features of joints, and their relationship to other structures (Figures 3 - 5). A comparison of the nomenclatures of Price and Balk is made in Table III. Burger and Thompson (1970) conducted a study wherein they determined whether or not fractures associated with the Carmichael Peak anticline in Madison County, Montana were due to the folding of the structure. In the study, Burger and Thompson (1970) collected strike and dip data for 150 fractures, at each of a number of "stations." The

TABLE II

PRIMARY JOINT NOMENCLATURE

Cross Joints (Q)	- in igneous rocks, those joints that are perpendicular, or nearly so, to primary flow lines; broadly, identical to tension joints in the earth's crust
Longitudinal Joints (S)	- strike parallel, or nearly so, to primary flow lines
Diagonal Joints	- strike at an angle of about 45 degrees to primary flow lines
Primary Flat Joints (L)	- flat-lying joints, embracing primary flow lines

Note: It should be noted that these primary joints do not necessarily always coincide with non-primary joints; i.e., joints not formed during the period of "consolidation" of an igneous body--W.C.H.

(After Balk, 1937)

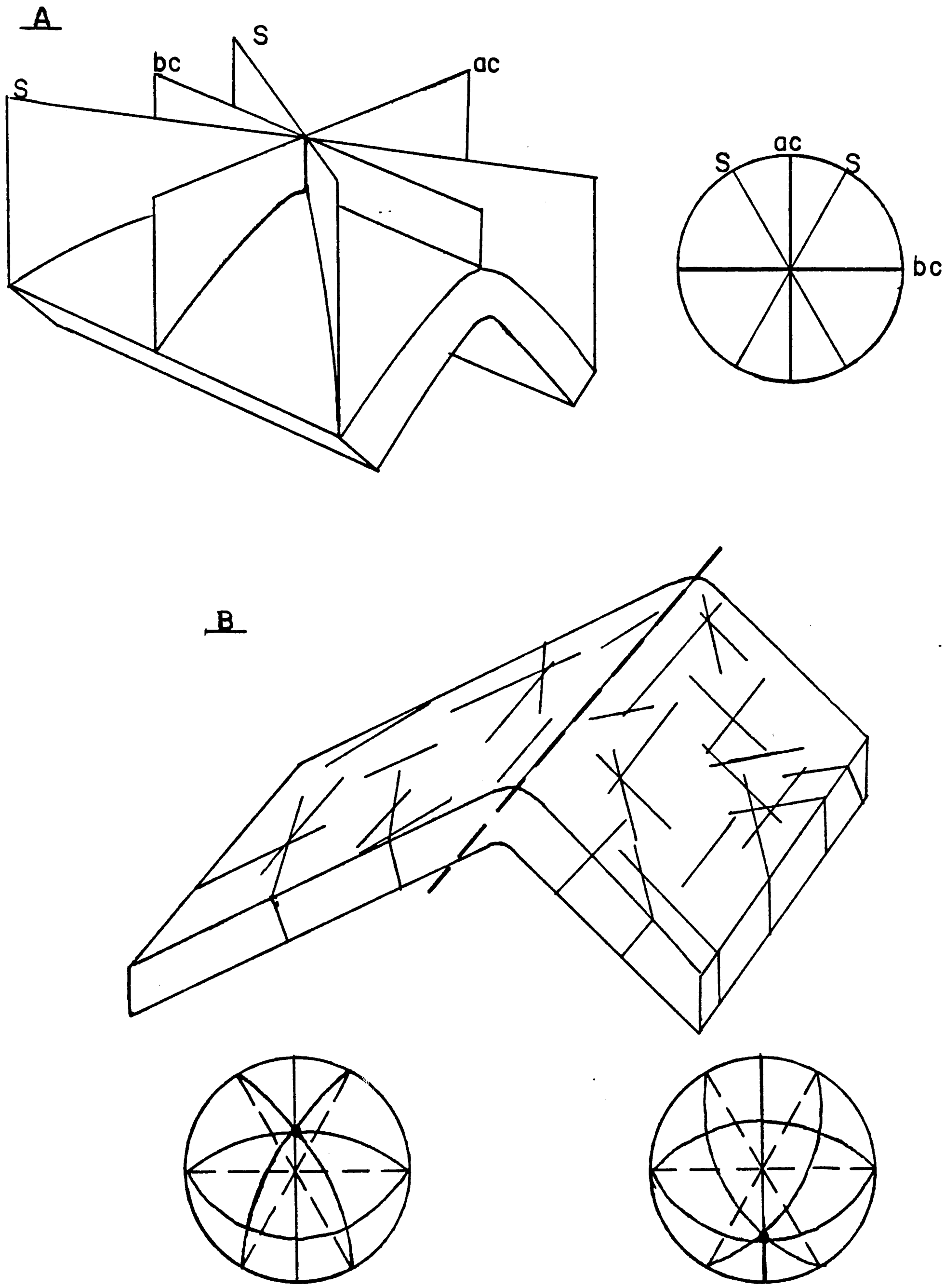

Figure 3. Block Diagrams and Stereograms Showing Typical Orientations of Master Joints in: (A) on Anticline, and (B) an Asymmetrical Anticline (After Price, 1966)

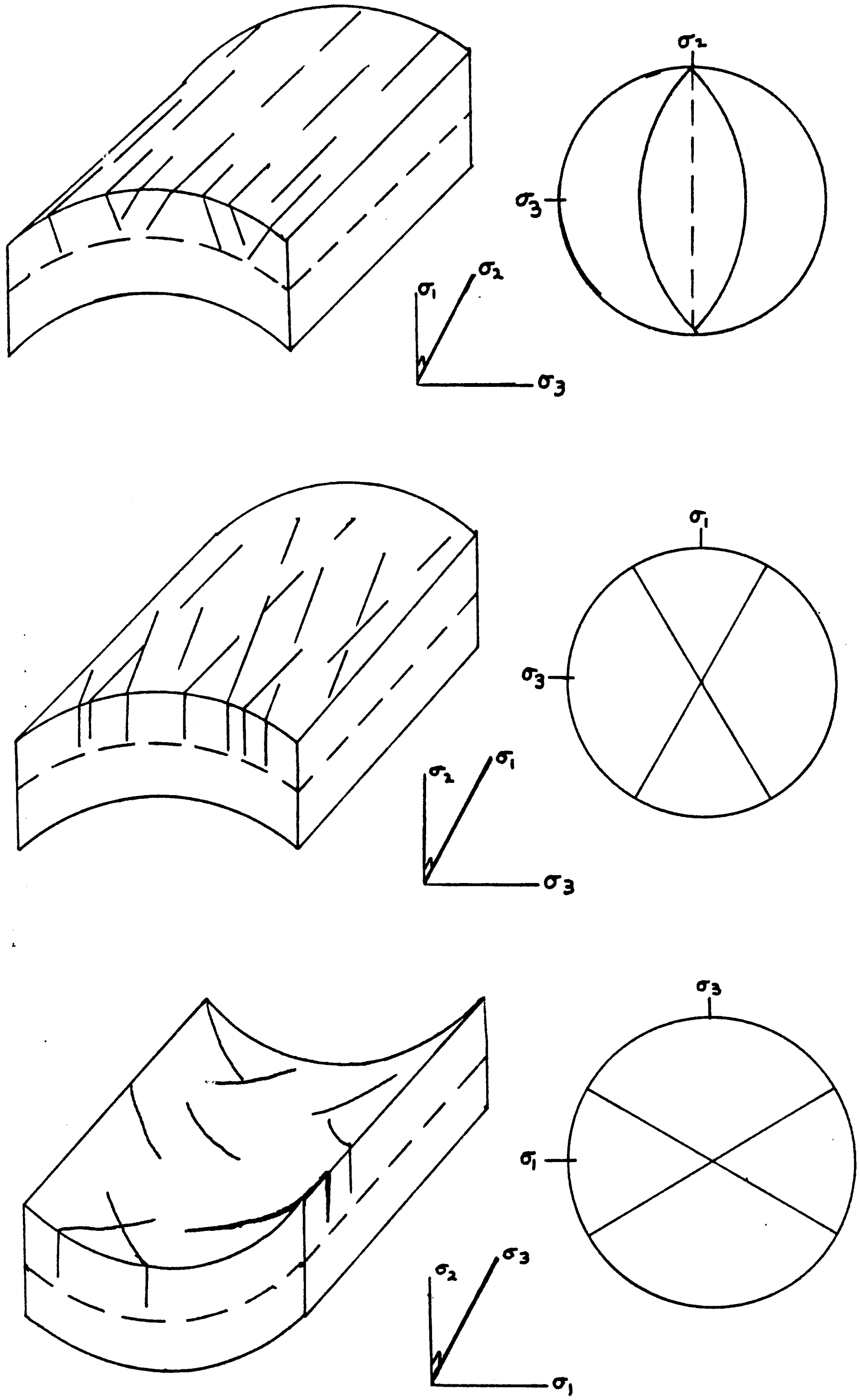

Figure 4. Relationship of Joints in Different Folds to Various Stress Orientations (After Price, 1966)

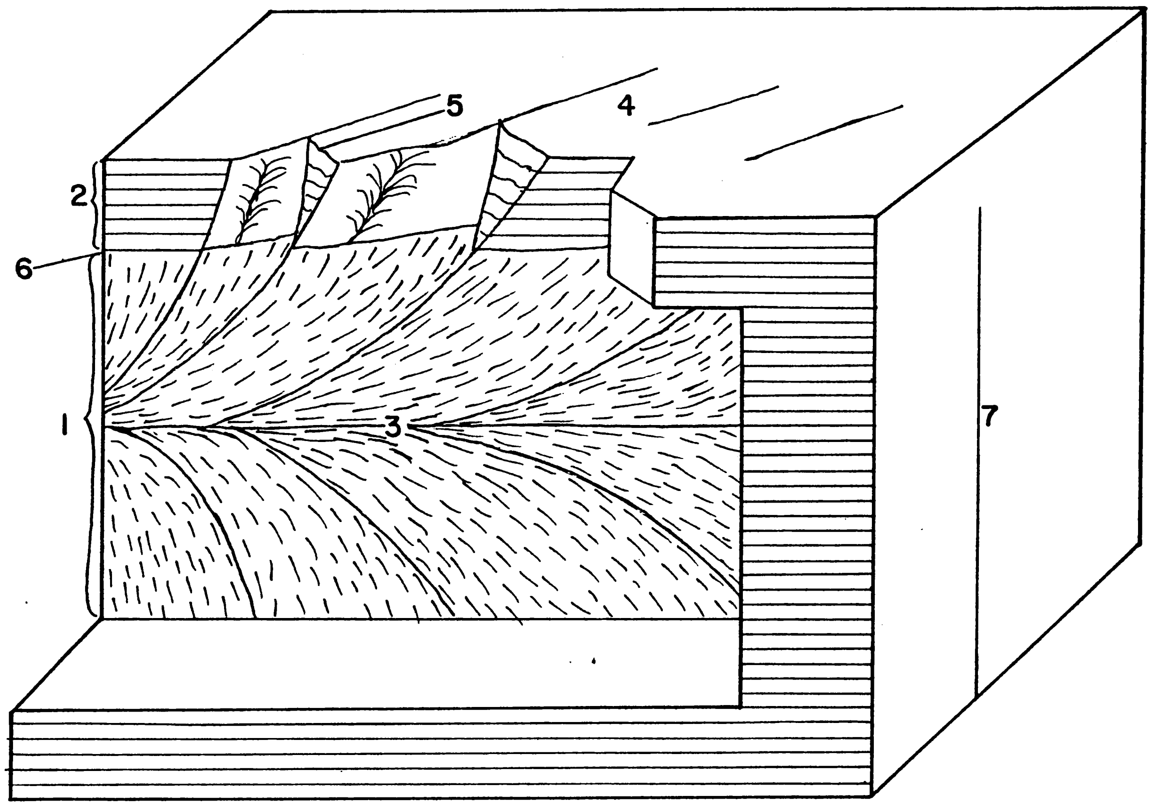

Figure 5. Details of Joint Surface Features: (1) Main Joint Face, (2) Fringe, (3) Plumose Structure, (4) Fringe Joints, (5) Cross Fractures, (6) Shoulder, and (7) Main Joint Trace (After Price, 1966)

TABLE III

COMPARISON OF NOMENCLATURES

Balk (1937)	Price (1966)
"Cross joints (Q)"	"a-c joints"
"Longitudinal joints (S)"	"a-b joints"
"Diagonal joints"	"s joints"
"Primary flat joints (L)"	

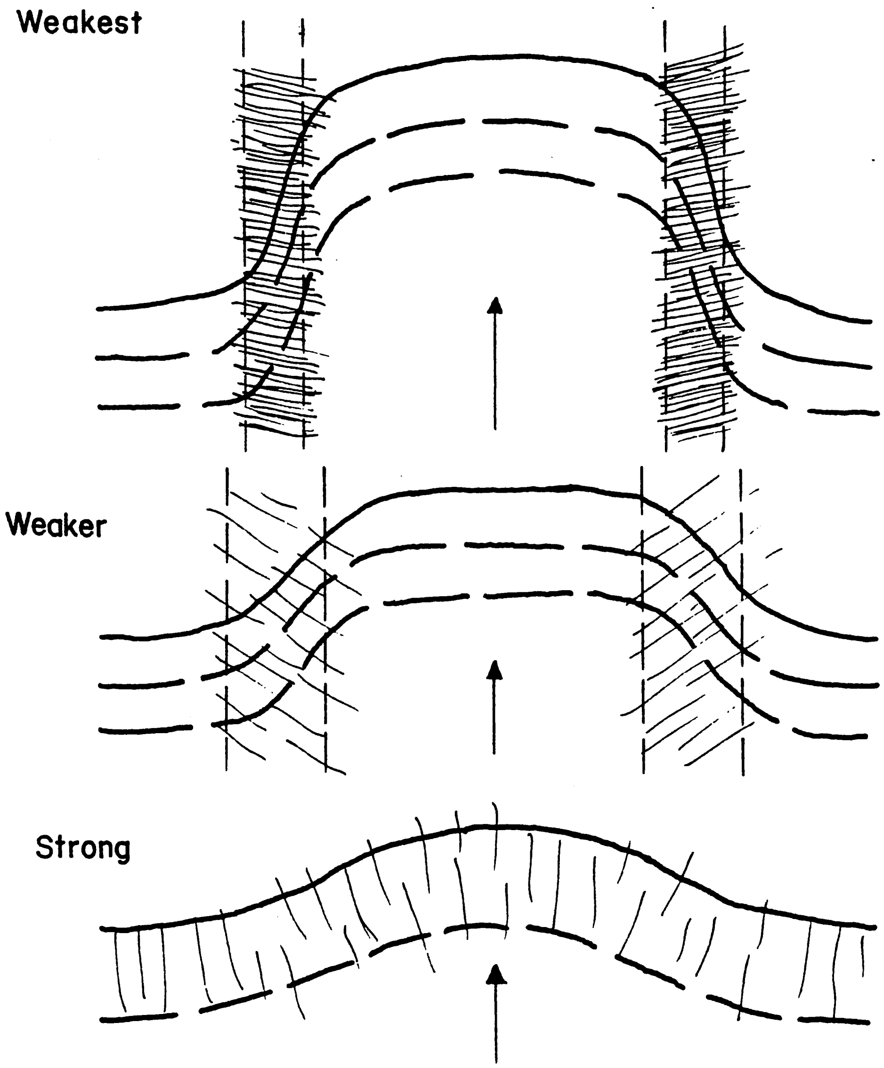

Figure 6. Bending of Weak and Strong Materials and Development of Marginal Fractures or Joint Fans; Tension Joints May Open in Intense Zones of Lengthening (Indicated by Dotted Lines) (After Balk, 1937)

orientation data were then plotted on an equal-area net; maximum concentrations were selected from each contour diagram (constructed from equal area net data), representing dominant fracture sets at each station. In his study of the structural development of the Hanover--Fierro Pluton in New Mexico, Aldrich (1974) identified five distinct joint sets. His methods were similar to those of Burger and Thompson (1970). Currie and Reik (1976) stated that

> . . . regionally important directions of jointing can be identified reliably by measurement of all joints observed at a group of exposures within that region, and following this by systematic processing of these measurements to produce a graphic profile of preferred joint-strike directions (p. 1226).

Thus, they offered a method useful for distinguishing between regional jointing and jointing directly attributable to diastrophic events associated with development of individual structures. Grout and Verbeek (1983) pointed out insufficiencies in the study of strike alone of joints, and suggested a technique that used multiple criteria to identify joint sets. Such criteria were the general "style" of the joints, and the relative age of the various sets. The "style" of a joint set involves such attributes as joint dimensions, overall configuration, type and character of surface markings, mineral fillings or coatings, spacings between adjacent members of a set, and the manner in which the joints terminate. Segall and Pollard (1983) studied joint formation in granitic rocks of the Sierra Nevada. In their report, they gave a method for estimating the tensile stress responsible for initiating joint growth. The method requires knowledge of the extensional strain accommodated by joint dilation and the spatial density of joints. Davis (1984) gave an excellent discussion of joints, as well as methods and explanations for collecting, recording, and mapping joint data. He (Davis) described two principle methods for collecting data:

1. Selection Method, involving selection of certain joints that are continuous and throughgoing, and are conspicuously associated with other joints of similar appearance and orientation.
2. Inventory Method, involving measurement of all joints at a single site.

(The selection method, with some aspects of the inventory method, was used in this study.) Davis also stated that when recording data, the following should be observed wherever applicable: site location, rock type, orientation of bedding or foliation, bed or layer thickness, type of joint or joint-related structure, and measurements pertinent to computing joint density (each of these, except joint density data, was observed as closely as possible and wherever applicable in this study). Methods of presenting and analyzing data suggested by Davis (and used in this study) involved the use of pole-density diagrams, rose diagrams and histograms.

Related Studies: Flow Structures

Cummings (1964) and Elston and Smith (1970) pointed out specific criteria for the determination of flow direction in rhyolite rock; these criteria mostly involve thin section examination. The criteria are: non-equidimensional and equidimensional fork-shaped glass shards, penetration effects, imbrication, blocking effects, spindle-shaped objects, and eddies in the fluidal texture (Figures 7 - 9). Smith and Rhodes (1972) used the criteria of Elston and Smith (1970) in flow direction analysis of quartz latite and andesite flows in the Mogollon Mountains of New Mexico.

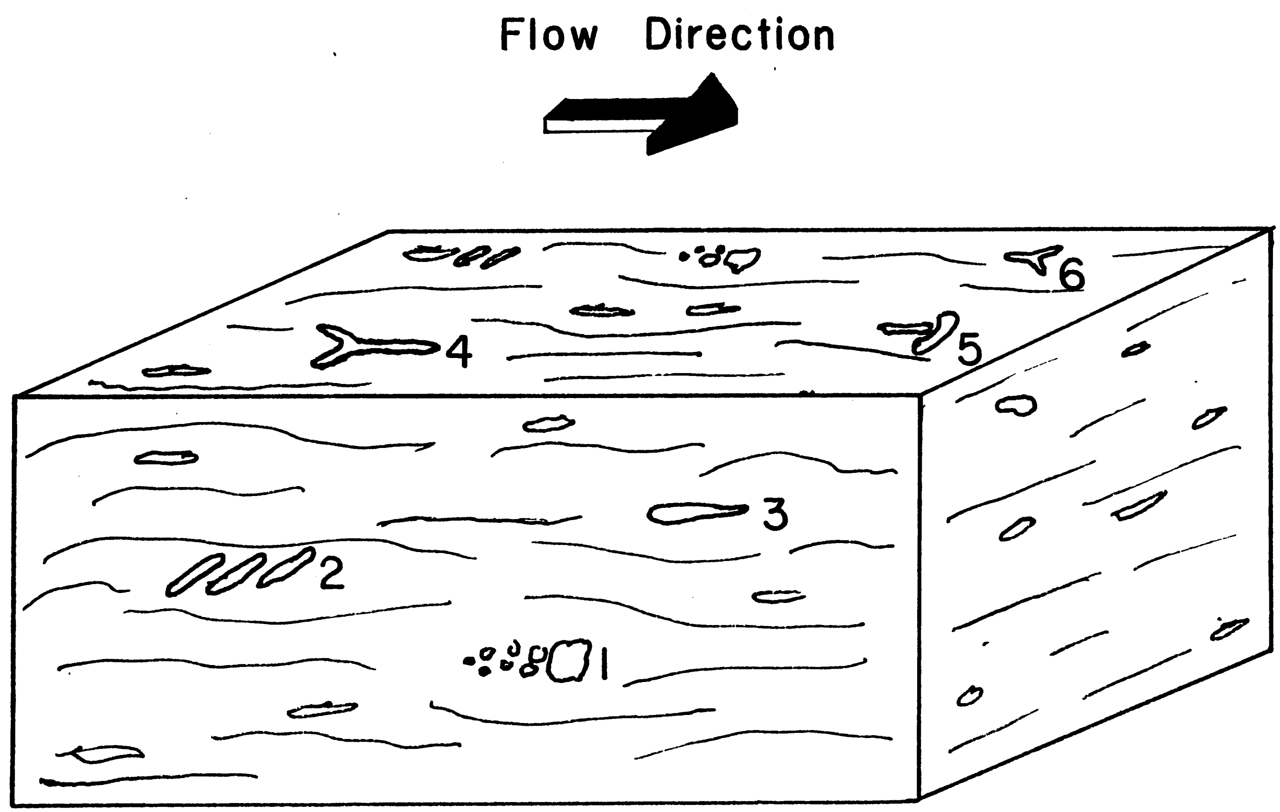

Figure 7. Flow Azimuth Criteria: (1) Blocking Effects, (2) Imbrication, (3) Spindle-shaped Crystal, (4) Non-equidimensional Fork-shaped Glass Shard, (5) Penetration Effect, and (6) Equidimensional Fork-shaped Glass Shard (After Elston and Smith, 1970)

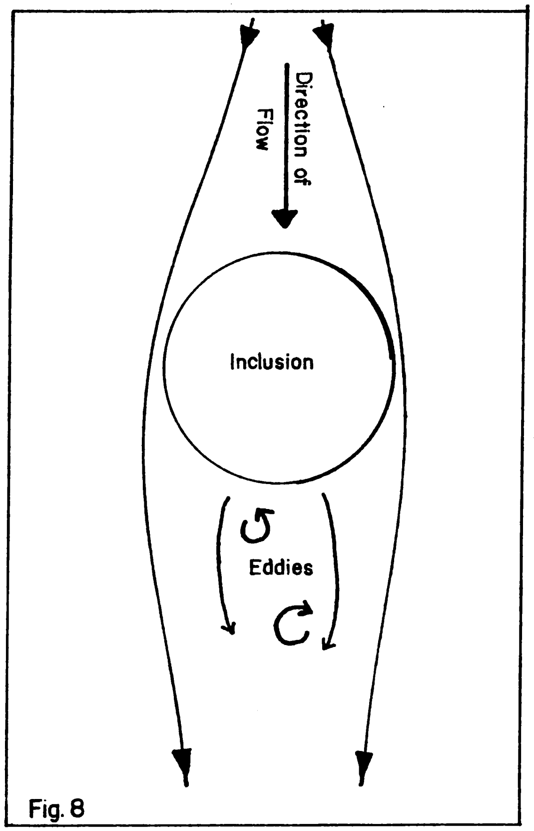

Fig. 8

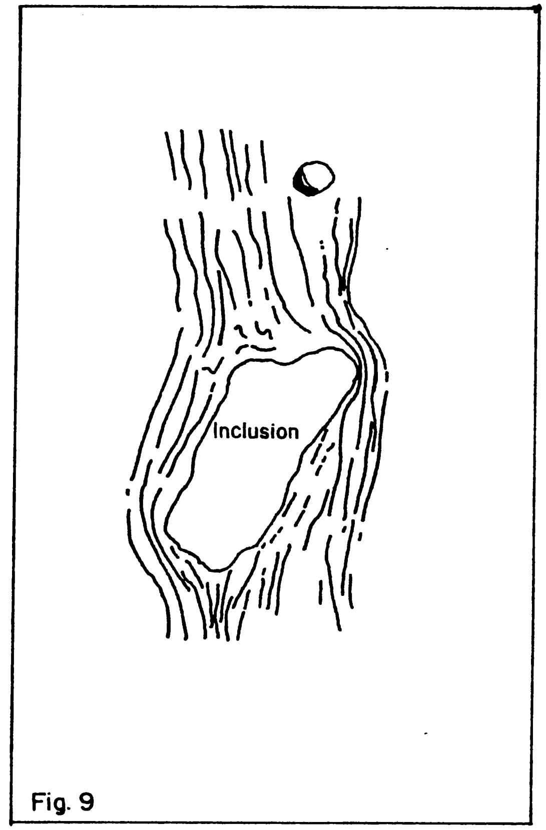

Fig. 9

Figures 8 & 9. Eddies as Indicators of Local Flow Direction: Figure 8 - Development of Eddies on Downflow Side of an Inclusion; Figure 9 - Trace of Photo of Eddy Zone in Rhyolite Outcrop; Eddy Zone in Top of Figure Indicates Flow From Bottom to Top (After Cummings, 1964)

Methods of Study Used in This Thesis

Fracture patterns were examined in two ways:

1. on an outcrop-to-outcrop basis in the field and
2. by study of aerial photography.

In both instances, joint (or lineament) trends were noted; however, when examining outcrops in the field, additional data were collected.

When examining an outcrop, it was first determined if the outcrop was of use (primarily, though not entirely on the basis of its size). Following this, if the outcrop was of use, the position of the outcrop was noted on a topographic map (if the outcrop was exceptionally large, several locations within it were chosen and noted on the map). Next, a visual examination of the location was made, accompanied by spot readings of joint trends, to determine the predominant joint trends. A circle drawn with chalk and string, with a diameter of six to eight feet was drawn at each location, and joints of each predominant set were examined within the circle. Data such as joint trend and dip, relative age (if discernible), and surface features (these were rare) were noted. If sheeting was present, its strike, dip, and average thickness were recorded. Flow lines, if present, were noted and their trends and plunges determined; such flow lines were comparatively rare. Other features, such as faults, dikes, and discernible differences in lithology of the rhyolite were recorded. Where necessary, oriented specimens were taken, and field sketches were made. At a few key outcrops, data pertaining to joint length, spacing, and intensity were recorded. Intensity was calculated using the method suggested by Wheeler and Dixon (1980) which produced an "intensity estimator". If by its nature an outcrop could not at least produce reliable trend and dip data for predominant joint trends, it was rejected.

Another means by which joints/lineaments were studied was examination of six-inch-to-one-mile scale air photographs of the study areas. A method was devised whereby the distribution of lineations, according to their trends, was weighted to allow for the varying length of the lineations. In this method, a one-mile (photograph scale) grid was constructed with divisions at 200-foot intervals, on a piece of clear acetate. Next, a trace map of lineations in the study area was made from the air photograph. Following this, the acetate grid was placed over the trace map, section by section; each time a lineation or part thereof was noted in a grid space, its trend was measured and recorded. Data were then transferred to a rose diagram.

Study of outcrop sheeting (layering) and compositional banding revealed that flow folding is common within exposures of the Carlton Rhyolite. In two specific cases, appearance of the flow folding was clear and extensive enough to warrant further examination. The first of these was in NW 1/4, NE 1/4, section 2, T4N R13W, in the Blue Creek Canyon area; within this area, sheeting orientation changed so often, without any indication of tectonic folding, that flow folding was clearly responsible for at least a majority of smaller-scale folding. The second area was on Zodletone Mountain, specifically NE 1/4, NE 1/4, section 17, T6N R14W. Here, the area was small enough to accommodate a field sketch, so a grid was set up on the ground using a measuring tape and compass, and using string to delineate the grid lines. Following this, a detailed sketch was made of the grid area, and sheeting readings were taken and recorded onto the grid area sketch (plate 6).

There were two methods by which fracture patterns were analyzed. They were:

1. a standard method, suggested by Davis (1984), whereby selected joints were measured, then analyzed on various diagrams, and
2. elements and concepts of a method, suggested by Currie and Reik (1976) wherein larger-, and smaller-scale joint systems may be distinguished. In this method, regional (larger-scale) joint sets or systems are defined as those whose relative proportion of readings is equal to or greater than about 10% of the entire number of readings, using all joint readings for the area in question. Larger- and smaller-scale joint sets or systems could then be distinguished, and causes of these joints could be more clearly and accurately determined.

CHAPTER II

GEOLOGIC FRAMEWORK

Aulacogens in Continental Lithosphere: General Statement

An aulacogen is a failed rift arm, part of a set of rift arms, usually though not always in a "triple junction" arrangement (Burke and Dewey, 1973; Figure 10). Burke and Wilson (1972) were the first to suggest that these triple junctions are formed over "hot spots" or convective plumes within the earth's mantle.

Convective motion in the earth's mantle is directly related to motion of lithospheric "plates" (McKenzie, 1983). New plate material is formed at a mid-ocean ridge and cools as the ridge continues to spread. Plate material is then subducted and sinks into the mantle because it is cooler and denser than the surrounding material. The motion of the cooler material downward forms the cold limb of a convection cell. Additionally, there must be an alternative, "hot" limb (plume) of the convection cell, wherein newly heated material rises. When the plume occurs beneath continental lithosphere, conditions become favorable for intracontinental rifting, from which an aulacogen may arise. Also possible is rifting which is roughly tangential to the swell in the earth's crust, associated with the plume (e.g., East African Rift System; Burke and Wilson, 1972). When the plume occurs beneath oceanic lithosphere, it may simply supply material to a mid-ocean ridge (McKenzie, 1983), or it may

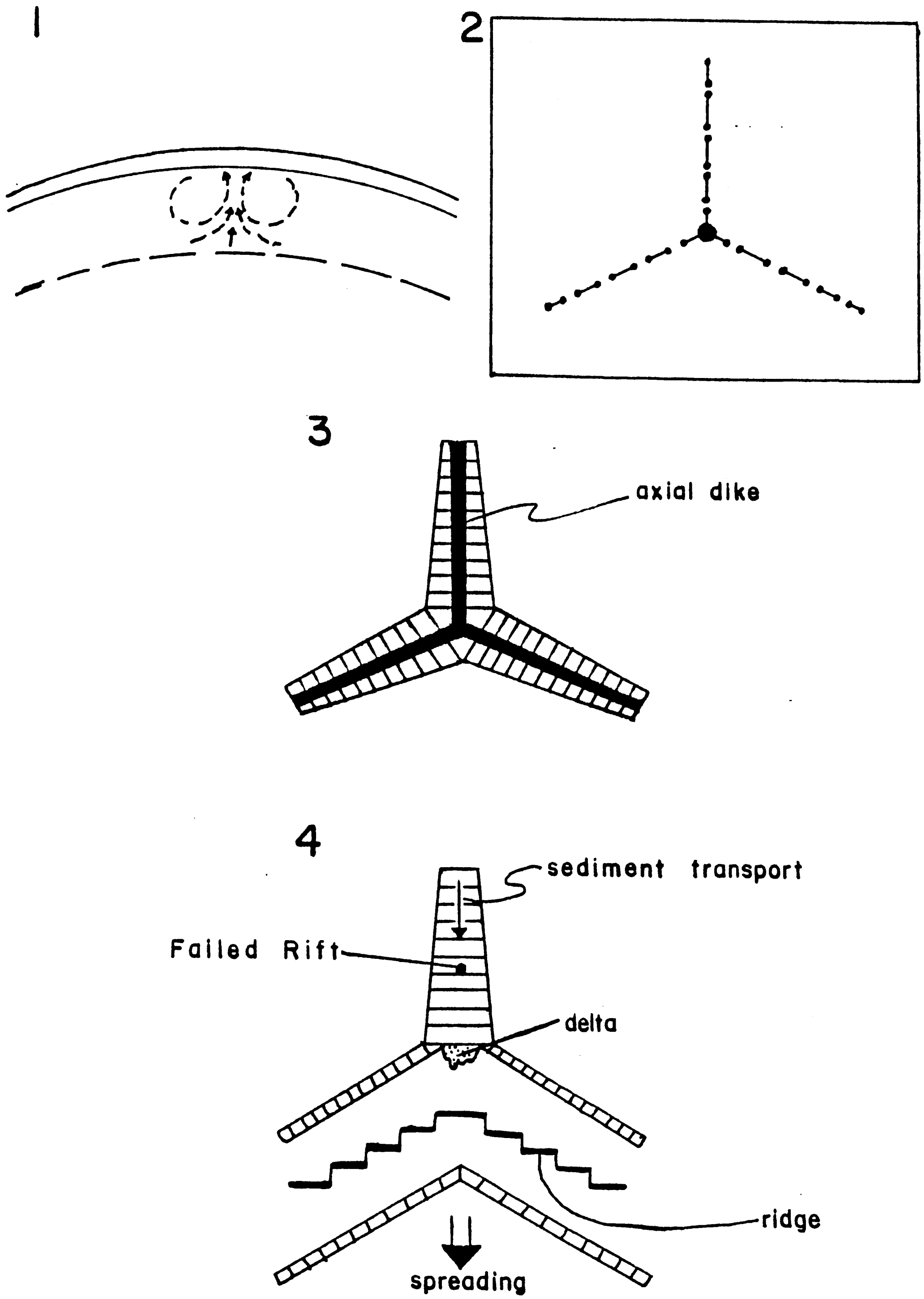

Figure 10. Stages in Evolution of a Failed Rift (aulacogen): 1) Mantle Plume Occurs, 2) Incipient Rifting, 3) Rift Valleys Develop, Meeting at "Triple Junction", 4) Two Rifts Spread as Third Rift Fails (Adapted From Burke and Dewey, 1973)

induce the formation of an intraoceanic volcanic arc, as in the case of the New Hebrides, Lesser Antilles, or Ionian Arcs (Reading, 1978).

During earlier stages of rifting, alkaline volcanism occurs usually as a series of intrusions and/or axial dikes in the rifts (Burke and Dewey, 1973). Later, further rifting usually occurs during the "spreading" stage of Burke and Dewey (1973). In a triple junction, this continued rifting occurs most often along only two of the rift arms. The third arm of the triple junction which fails to continue the rifting process is called an aulacogen. In some cases, a major river and major delta may occupy the failed rift. An example of this is the Niger River and its delta at the seaward end of the Benue Trough, which extends northeastward from the Gulf of Guinea reentrant in the bight of Africa. The Benue Trough began as an early Cretaceous graben that developed during the initial rift separation of Africa and South America, but ceased spreading shortly thereafter (Hoffman, Dewey, and Burke, 1974). In other cases, complex sedimentary/igneous/structural relationships may develop (Figure 11). Indeed, even large fluid hydrocarbon accumulations may be found in such failed rifts (e.g., Southern Oklahoma Aulacogen; specifically the Anadarko Basin in the aulacogen). In still other cases, failed rifts may be indicated by only a line of alkaline volcanic intrusions (e.g., lower Limpopo structure, which ceased to function before spreading occurred; Burke and Dewey, 1973).

Southern Oklahoma Aulacogen

Prior to the development of the Southern Oklahoma Aulacogen, it is possible that a Proterozoic basin existed to the south of the present aulacogen and perhaps beneath the present Wichita Mountains

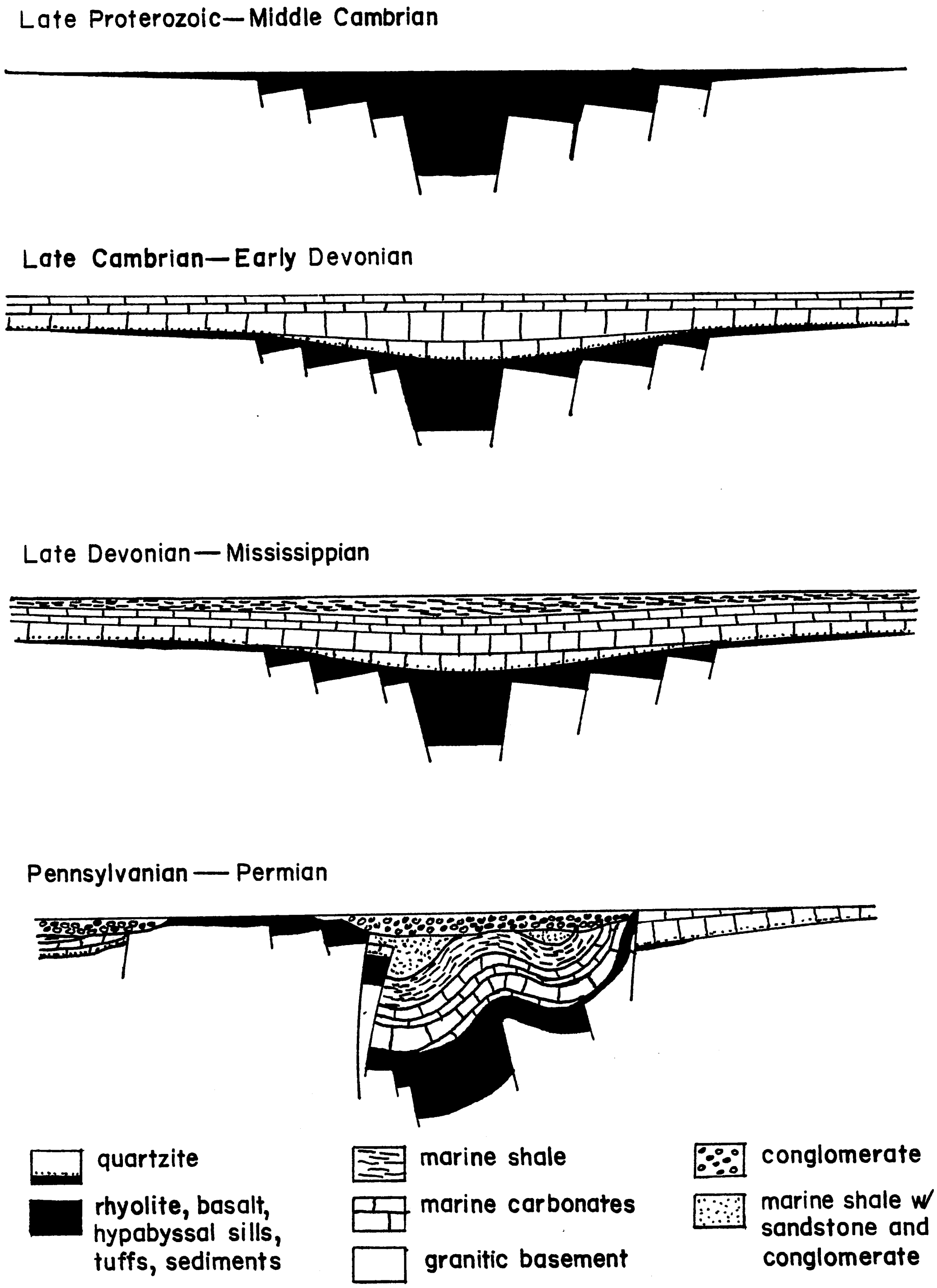

Figure 11. Series of Schematic Cross Sections Showing Evolution of Southern Oklahoma Aulacogen (Redrawn From Hoffman et al., 1973)

(Brewer, 1982; Figure 12a). The chief evidence for a Proterozoic basin is the presence of distinct reflections in seismic profiles made by COCORP. According to Brewer (1982), the character of the reflections suggests depositional processes, as there are suggestions of angular unconformities with onlapping, and downlapping relationships developed. Brewer (1982) also suggested that the Tillman Metasedimentary Group (age: 1.0-1.3 b.y.(?); Gilbert, 1983) may comprise part of the suggested layering, and that a possible fault zone partially bounded the basin to the north.

The first evidence for rifting is found in the basaltic intrusive rocks of the Glen Mountains Layered Complex (Gilbert, 1983; Figure 12b). The extrusive equivalent of the Glen Mountains Layered Complex is the Navajoe Mountain Basalt-Spillite Group. These basalts, found only in the subsurface, were shallow submarine flows (Shapiro and Sides, 1982; Figure 12b). The structure of the aulacogen in its beginning was probably graben-like, with the Glen Mountains layered complex partially filling the graben (Gilbert, 1983). Block faulting of this sort might be expected following domal uplift due to mantle plumes (Burke and Wilson, 1972). A later basaltic magma formed the series of layered plutons known as the Roosevelt Gabbros. This group intruded the Glen Mountains Layered Complex, and quite possibly the Tillman metasediments (Bowring and Hoppe, 1982; Figure 12c). It has been suggested that the emplacement of these plutons in the Wichita Block stabilized the block and gave it a gross structural integrity (Gilbert, 1981, 1984). Uplift occurred shortly after, or during emplacement of the Roosevelt Gabbros, and erosion removed 2-3 km of overburden and gabbro (Powell and Phelps, 1977). Sides and Miller (1982) and Gilbert (1982) stated that the late

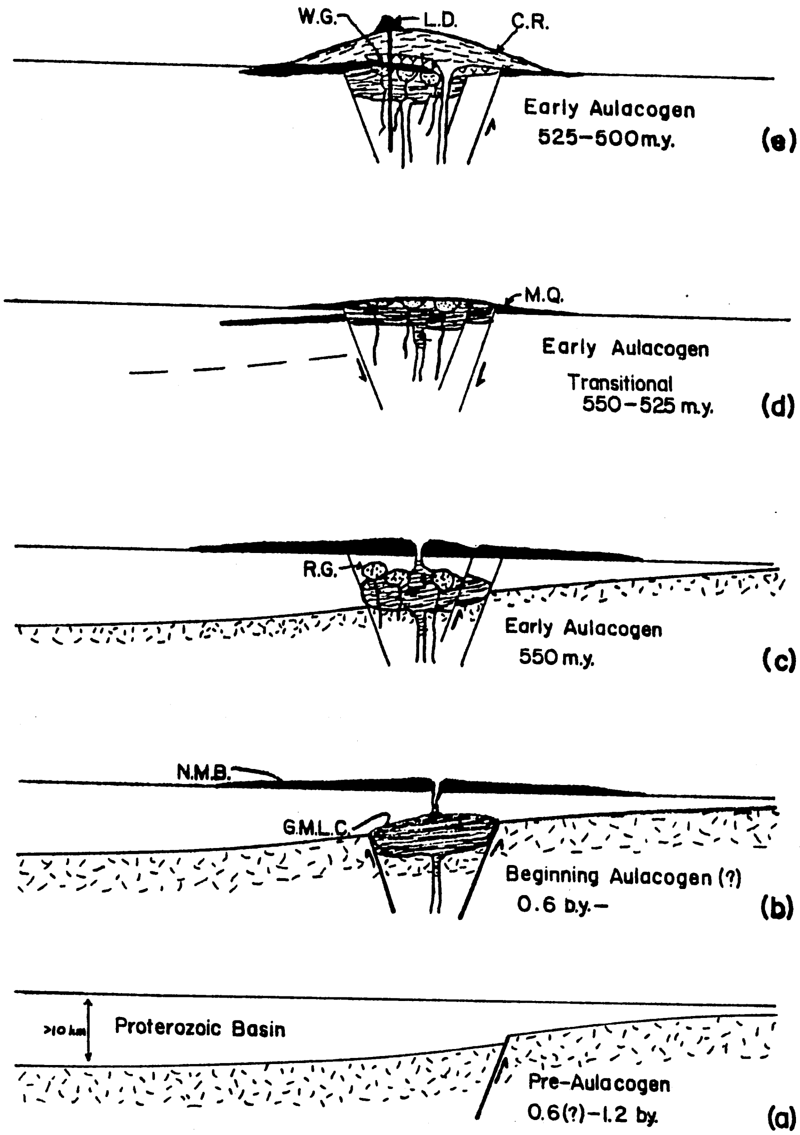

Figure 12. Pre-sedimentary Development of the Southern Oklahoma Aulacogen: G.M.L.C. = Glen Mountains Layered Complex; N.M.B. = Navajoe Mountain Basalt - Spillite Group; R.G. = Roosevelt Gabbros; M.Q. = Meers Quartzite; W.G. = Wichita Granites; C.R. = Carlton Rhyolite; L.D. = Late Diabase (Redrawn from Gilbert, 1983)

Proterozoic-early Cambrian Meers Quartzite was then deposited above the unconformity (Figure 12d). However, earlier authors, e.g., Ham, et al. (1964), considered the Meers Quartzite to be part of the Tillman Metasediments.

The extrusion of the Carlton Rhyolite Group was the next volcanic event (Figure 12e). It was accompanied by the intrusion of the co-genetic Wichita Granite Group. Timing of this phase of igneous activity was about 525 m.y.a. (Middle Cambrian time; Ham et al., 1964; Table I). The areal extent of the Carlton Rhyolite Group, along with its subsurface equivalents, covers an estimated 17,000 square miles, making these rocks the most widely distributed basement rocks in the region (Ham et al., 1964). The extrusion of the Carlton Rhyolite Group was probably associated with rift development, as its distribution parallels the trend of presumed bounding fault zones (Ham et al., 1964).

The final volcanic event in the development of the aulacogen is represented by late diabasic dikes which cut all other igneous units, but do not cut the Upper Cambrian Reagan Sandstone (Figure 12e). This group of dikes has been known since the work of Shumard (1852); their intrusion marks the cessation of igneous activity.

A long period of subsidence followed, wherein 4-5 km of lower and middle Paleozoic sediments accumulated (Figure 13a). In the Wichitas, the initial sediments were deposited in an onlapping fashion around the low hills formed in the Carlton Rhyolite. The Timbered Hills Group (Cambrian) consists of sandstone and limestone which record gradual marine inundation of an ancient land surface and eventual establishment of a highly productive carbonate shelf (Donovan et al., 1983). The Arbuckle Group (Cambrian Ordovician) consists chiefly of limestone (with

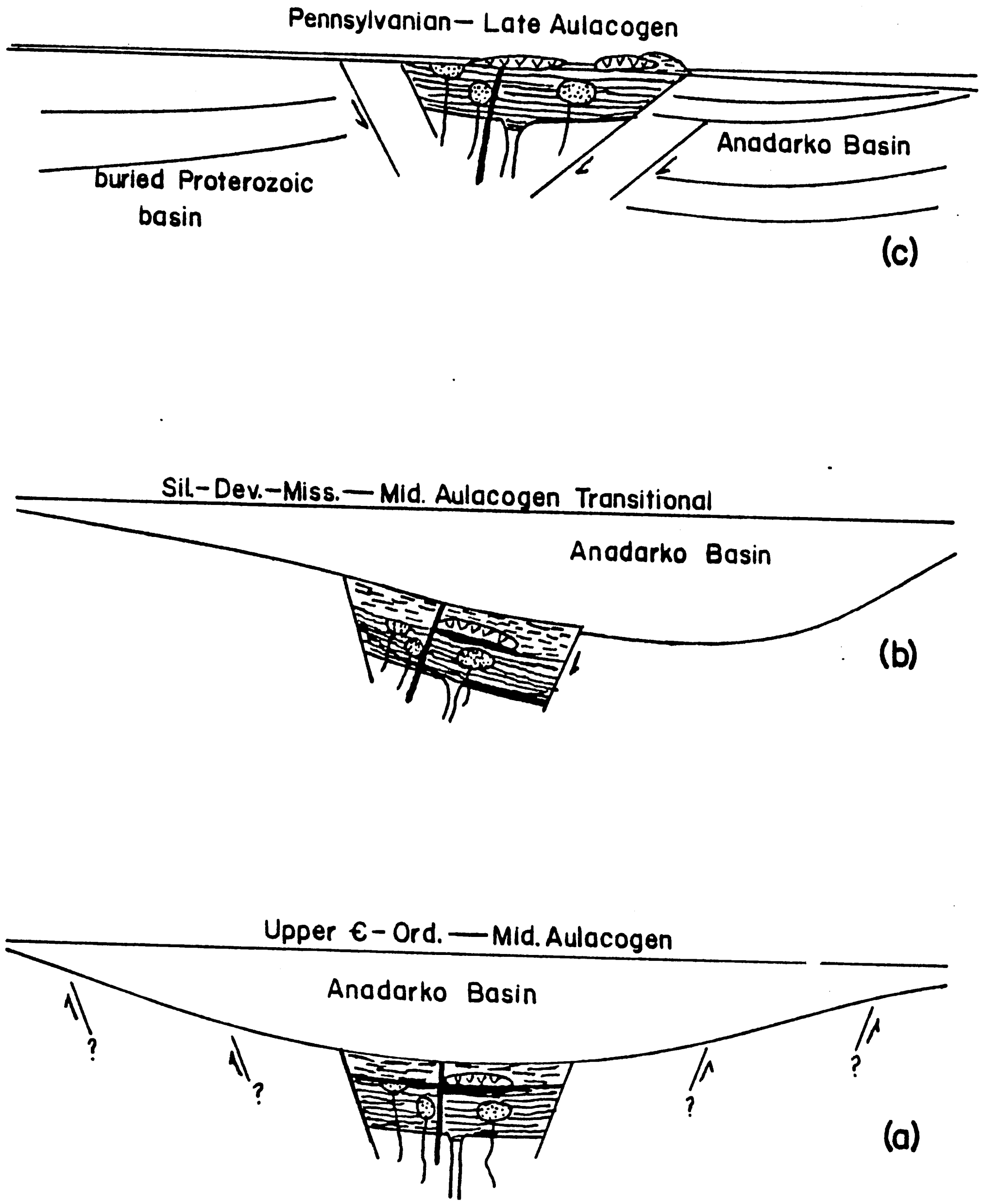

Figure 13. Depositional and Uplift Development of the Southern Oklahoma Aulacogen (Redrawn from Gilbert, 1983)

some dolomite) and variable amounts of chert, shale, and sand (Donovan et al., 1983). The Simpson and Viola units (Ordovician) consist chiefly of carbonate muds, while the Hunton and Woodford units are mixtures of shelf carbonates and clean sands punctuated by a number of unconformities (Gilbert, 1983). Kinderhook through Springer units (Mississippian) are represented by a series of thick shales and limestones (over 4000 feet thick in the north Gotebo area (Johnson and Denison, 1973; Figure 13b).

Beginning in Pennsylvanian time, collision of the North American plate with an inferred island arc or continent to the south resulted in crustal shortening and formation of the Ouachita orogenic belt (Brewer, 1982). In the Early Pennsylvanian, the first of two main orogenic episodes caused the Wichita Mountains region to become an area of major uplift. One suggested cause for the uplift was deep-rooted thrusting (Gilbert, 1983). Also during this episode, termed the "Wichita Orogeny" by Ham and Wilson (1967), the Anadarko, Ardmore and Marietta basins were downwarped, resulting in intense local deformation of the sediments therein. Further deformation occurred in the second main episode of orogeny, termed the "Arbuckle Orogeny" by Ham and Wilson (1967) in Late Pennsylvanian time. During this episode, previously active features were further deformed, and uplift of the Arbuckle Mountains occurred. Left-lateral wrench faulting has been postulated as a result of the thrusting of the Ouachitas against the foreland (Gilbert, 1983). According to Thomas (1973), the Ouachita orogenic event was essentially coeval with the Southern Appalachain structural system. Sedimentation in the Anadarko Basin during this time consisted of 4-5 km of Pennsylvanian sediments. Later, in Permian time, a further 4-5 km of debris, seemingly derived from the east, was deposited in the Anadarko Basin (Gilbert, 1983). Included in this debris was the Post Oak Conglomerate, which can be seen to overstep and overlap lower Paleozoic rocks exposed in the Blue Creek Canyon area (Donovan et al., 1983; Figure 14).

Summary

In summary, the Wichitas record a local Pennsylvanian reactivation of structural elements of the Southern Oklahoma Aulacogen. The aulacogen probably overlies an earlier Proterozoic basin. During its formation, there were two basic igneous events (the second of which gave the Wichita block a gross structural integrity), followed by a granitic/rhyolitic event, and finally a third basic event. Slow subsidence and deposition then followed, until Pennsylvanian time, when the Ouachita orogenic event occurred, during which the Wichita and Arbuckle Mountains were formed. In coeval basins adjacent to the mountains up to 9 km of Pennsylvanian and Permian sedimentation took place. Subsequent erosion has revealed the Wichitas' topography as an exhumed land surface upon which Pennsylvanian and Permian sediments can be seen to lap.

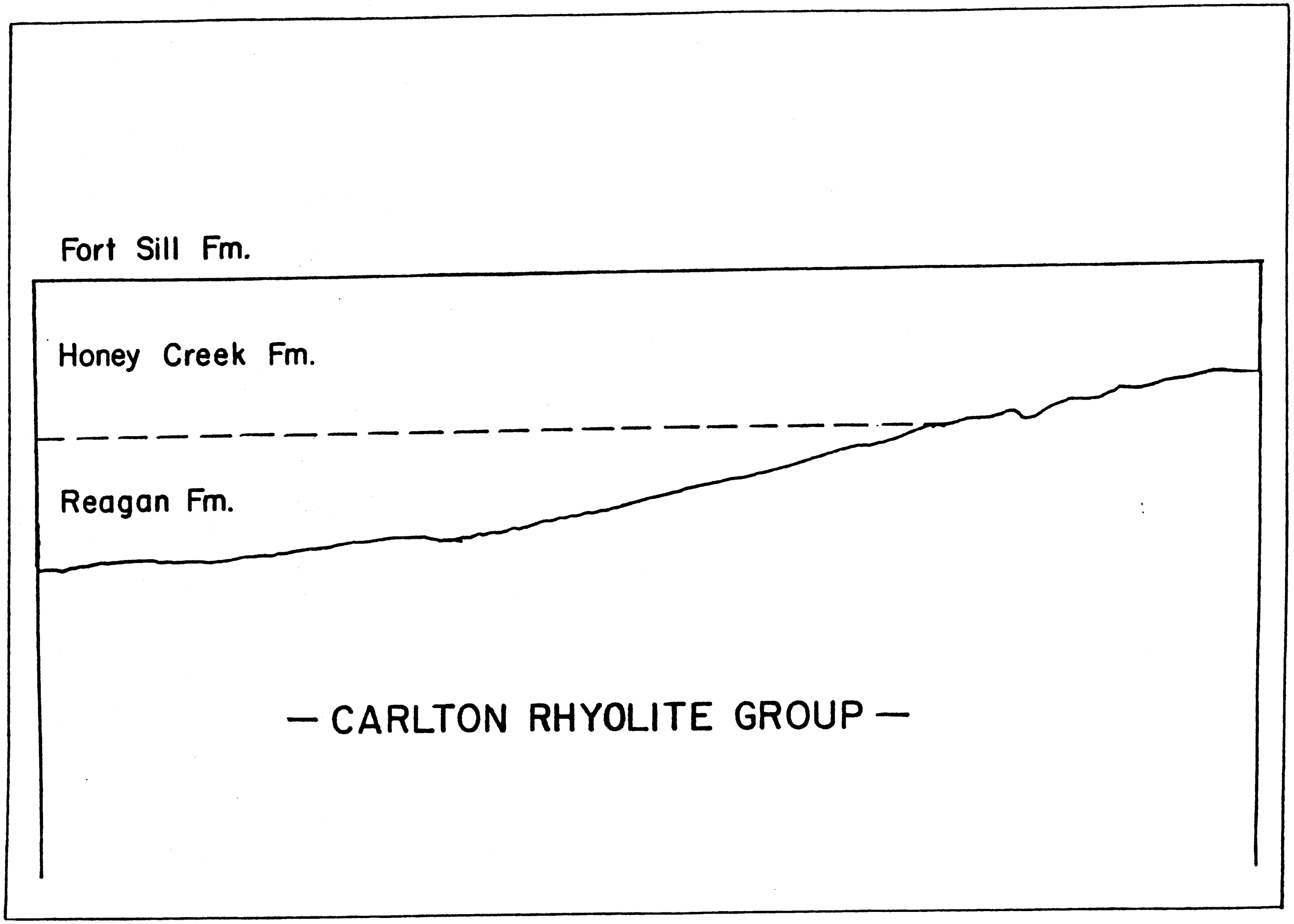

Figure 14. Schematic Diagram Showing Overlap (Onlap) Relationships in Blue Creek Canyon (Redrawn From Donovan, 1982)

CHAPTER III

DISTRIBUTION AND GEOLOGIC RELATIONS

Distribution

According to Ham et al. (1964), the Carlton Rhyolite and its subsurface equivalents originally occupied a total area of at least 17,000 square miles. This area was composed of a principle segment extending northwestward along the Anadarko Basin, into the Texas panhandle (an area of about 15,000 square miles), and an additional area suggested by two outliers, in western Greer and east-central Jackson Counties (an area of about 2,000 square miles). So extensive is the rhyolite, that its original area extended beyond the confines of the bounding fault zones of the southern Oklahoma aulacogen (Gilbert, 1984).

The rocks of the Carlton Rhyolite Group are part of an enormous volcanic field. The rhyolite sequence has a maximum drilled thickness of 4,500 feet in the Frankfort Sparks well in western Murray County, and a maximum exposed thickness of 3,600 feet at Bally Mountain, in northeastern Kiowa County (Ham et al., 1964).

Where the Carlton Rhyolite Group outcrops in the Wichita and Arbuckle Mountains, it consists of a stratiform sequence of rhyolite flows, tuffs, and agglomerates. Principle outcrops of the Carlton Rhyolite exist in: (a) a low range of hills within the Fort Sill military reservation near Lawton, Oklahoma; (b) the Blue Creek Canyon area, located in the Limestone (Slick) Hills area northwest of Lawton;

(c) the Bally Mountain/Zodletone Mountain area, also northwest of Lawton; and (d) the East and West Timbered Hills of the Arbuckle Mountains in south-central Oklahoma (here, the rhyolite was termed the "Colbert Porphyry" by Reeds (1910)).

Geologic Relations

At its lower boundary, there is an unconformity between the rhyolite and gabbros of the Roosevelt and the Glen Mountains Layered Complex. At its upper boundary, an irregular unconformity exists between the rhyolite and the Timbered Hills Group (Figure 159 <u>in</u> Donovan et al., 1982). After extrusion of the rhyolite, sediments of the Timbered Hills and Arbuckle Groups were deposited in such a way that they developed an overlapping relationship upon the rhyolite (Figure 14). The Permian Post Oak Conglomerate also exhibits this overlapping relationship, not only with the rhyolite, but also with all other Paleozoic sediments, in Blue Creek Canyon.

The nature of the relationship between the Carlton Rhyolite Group and the Wichita Granite Group is best summed up by Ham et al. (1964) who stated

> Extrusion of the volcanic rocks (rhyolite) was contemporaneous with crystallization of the Wichita granites at shallow depth. The period of formation of this intrusive-extrusive series was long continued, and at many localities the early phases of rhyolite, principally the basal part of the Carlton Group, are extensively injected by granite and are locally altered, or converted to hornfels. The reverse age relation, that of granite injected by (late) intrusive rhyolite, also is known at a few localities (p. 39).

One example of rhyolite cutting granite can be seen in SW 1/4, NW 1/4, NW 1/4, Sec 20, T3N R12W (Ham et al., 1964). The reverse relationship can be seen at NW 1/4, Sec 14, T3N R13W (Gilbert, 1982).

Summary

In summary, the rocks of the Carlton Rhyolite Group are part of a large volcanic field which borders the Anadarko Basin. The extent of the field goes beyond the confines of fault zones bounding the southern Oklahoma aulacogen. Maximum known thickness of the rhyolite is 4,500 feet. Principle exposures of the rhyolite are seen near and northwest of Lawton, Oklahoma, in the Wichita Mountains and in the Arbuckle Mountains. The upper and lower surfaces of the rhyolite are marked by unconformities. Finally, the Carlton Group and the Wichita Granites have a co-genetic relationship wherein rhyolite is injected by granite, and granite is injected by rhyolite.

CHAPTER IV

RESULTS OF STUDY

Introduction

The contents of this chapter are results stemming from analysis of field data and aerial photography covering the Blue Creek Canyon and Bally Mountain/Zodletone Mountain areas. There are three main results:

1. inference of a previous (Cambrian) structural grain,
2. inference of a later (Pennsylvanian) structural grain, and
3. inference of a large tectonic fold in the Carlton Rhyolite, east of State Highway 58 in the Blue Creek Canyon area.

Previous (Cambrian) Structural Grain

Analysis of joint orientation data (in the Carlton Rhyolite), for the whole Blue Creek Canyon area, and smaller areas within it, as well as study of aerial photography and topographic maps, suggests the presence of pre-Reagan Sandstone structural grain. Principle evidence suggesting this structural grain is located in the area of Turtle Creek (SW 1/4, NE 1/4, Sec 13, T4N R13W to SW 1/4, NE 1/4, Sec 12, T4N R13W).

For most of its observed length, Turtle Creek runs along a fault. There are three main points of evidence to suggest this fault. Firstly, the creek appears to be unusually straight for a creek of its length (approximately 1 mile). This attribute is clearly visible from aerial photographs and topographic maps (Plate 2) as a major lineament in the Blue Creek Canyon area. It is unlikely that random erosion could have produced such a lineament. Hence, it is inferred that the stream is subsequent to the lineament. Secondly, at several places along the stream, there exist sharply defined joints which have smooth surfaces and are fairly straight. These joints run north-south, paralleling the stream. The joints range in length from one meter to several meters. Thirdly, near a small dam across the creek, located approximately at NE 1/4, SW 1/4, NE 1/4, Sec 13, T4N R13W, there is a swarm of quartz-filled veins oriented at an angle of about twenty-one degrees to the Creek. The veins trend approximately 159 degrees (Figure 15). It is reasonable to expect (at least locally) that the principle compressive stress was oriented roughly parallel to the veins. Hence, a left-lateral sense of shear across the Turtle Creek is implied. One noteworthy aspect of the veins is their less-than expected angle to the shear zone. In theory (Ramsay, 1967, Hobbs et al., 1976), such features would be expected to originate at an angle of about forty-five degrees to the shear zone. In reality, this is almost never the case. Due to the cohesive strength of the material, such features normally propagate at an angle of about thirty degrees to the shear zone. Three possibilities exist to explain the unusually low angle of the veins to the shear zone:

1. the rhyolite possesses a higher than normal amount of cohesive strength, thus causing a higher angle of internal friction, and consequently, a lower angle of vein propagation;
2. there has been some rotation of the veins, due to continued strain along the shear zone, to a lower angle with the shear zone; and

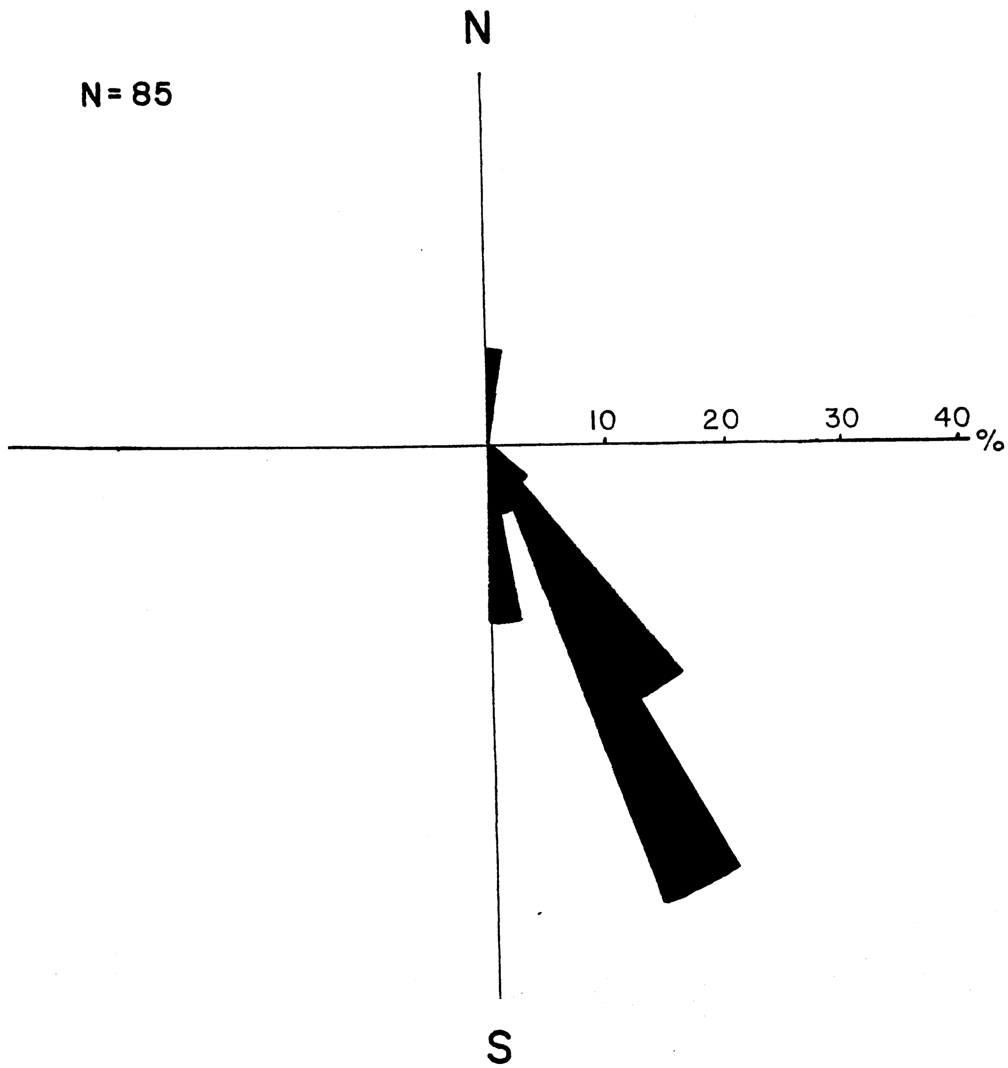

Figure 15. Diagram Illustrating Orientations of Quartz Veins Near Turtle Creek

3. the veins are due to some cause other than the supposed fault, and hence, are totally unrelated to the fault.

The first possibility seems the most likely one. This is because recorded rupture angles in compression tests have been as low as twenty-four degrees (rhyolite at Tishomingo, OK; Grigs and Handin, 1966). If rotation of the veins had occurred, it would have increased the angle between vein and shear zone. Furthermore, the veins would have become, to some degree, sigmoidal in shape (which they are not). Hence, it is reasonable to assume that these extensional features propagated at or near a twenty-one degree angle with the shear zone.

Apparently associated directly with the "Turtle Creek Fault" is a set of joints whose trends vary between azimuths 000 and 030. These joints are thought to be associated with the Turtle Creek Fault for several reasons:

1. analysis of joints, from stations on and in the near vicinity of Turtle Creek, shows a comparatively high percentage of joints between azimuths 010 and 030 (Figure 16; see Appendix);
2. analysis of joints from rhyolite exposures along Ketch Creek shows a significant percentage of joints between azimuths 020 and 030, although this percentage is less than in the vicinity of Turtle Creek (Figure 17; see Appendix); and
3. analysis of joints from rhyolite exposures along and in the near vicinity of the Blue Creek Canyon Fault indicates that although joints between azimuths 000 and 020 are present, they do not constitute a significant mode (Figure 18; see Appendix).

It seems likely, therefore, that the influence of the "Turtle Creek trend" does decrease away from the creek. Furthermore, a similar trend

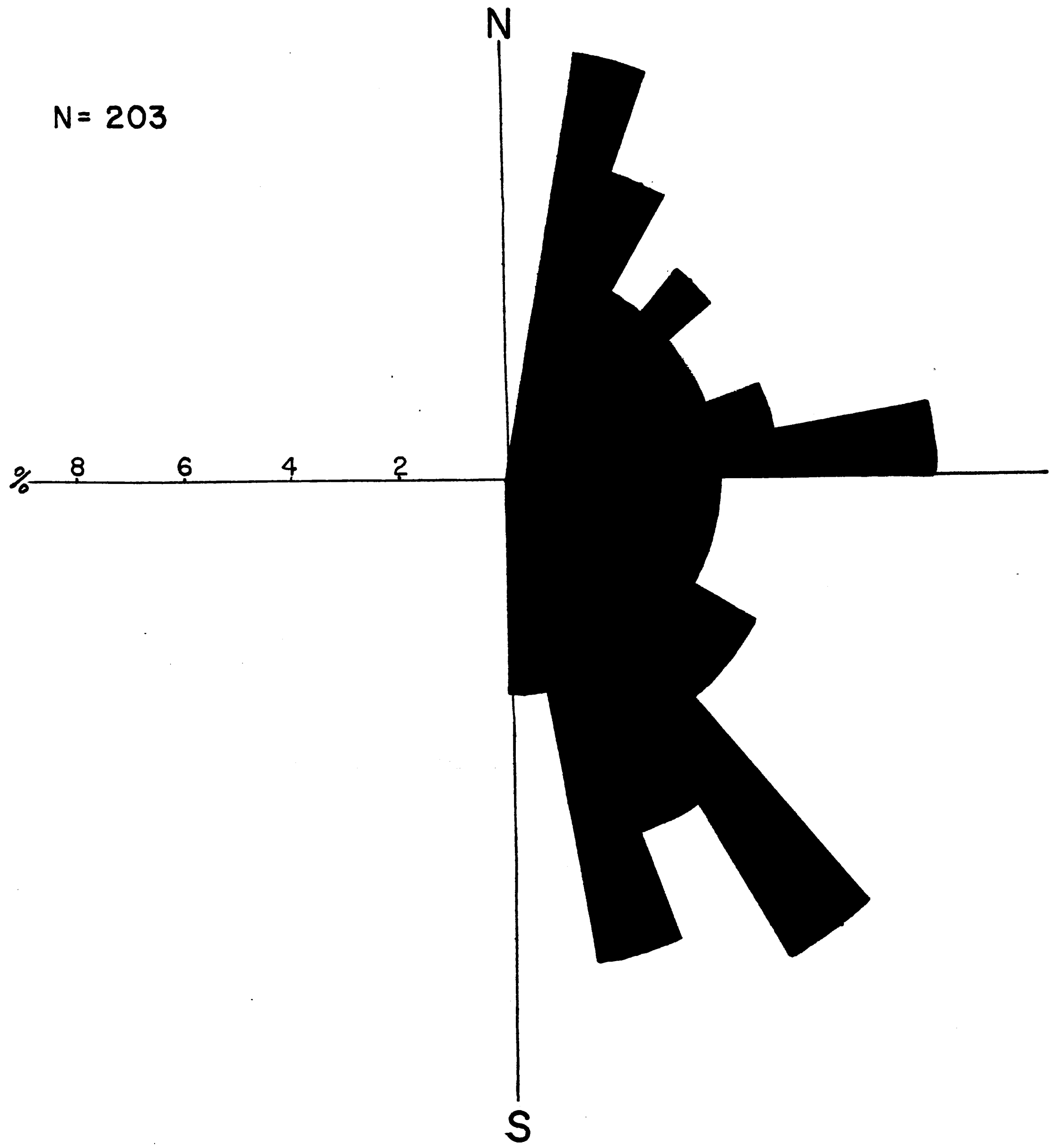

Figure 16. Rose Diagram Illustrating Distribution of Joint Trends in Area of Turtle Creek Fault

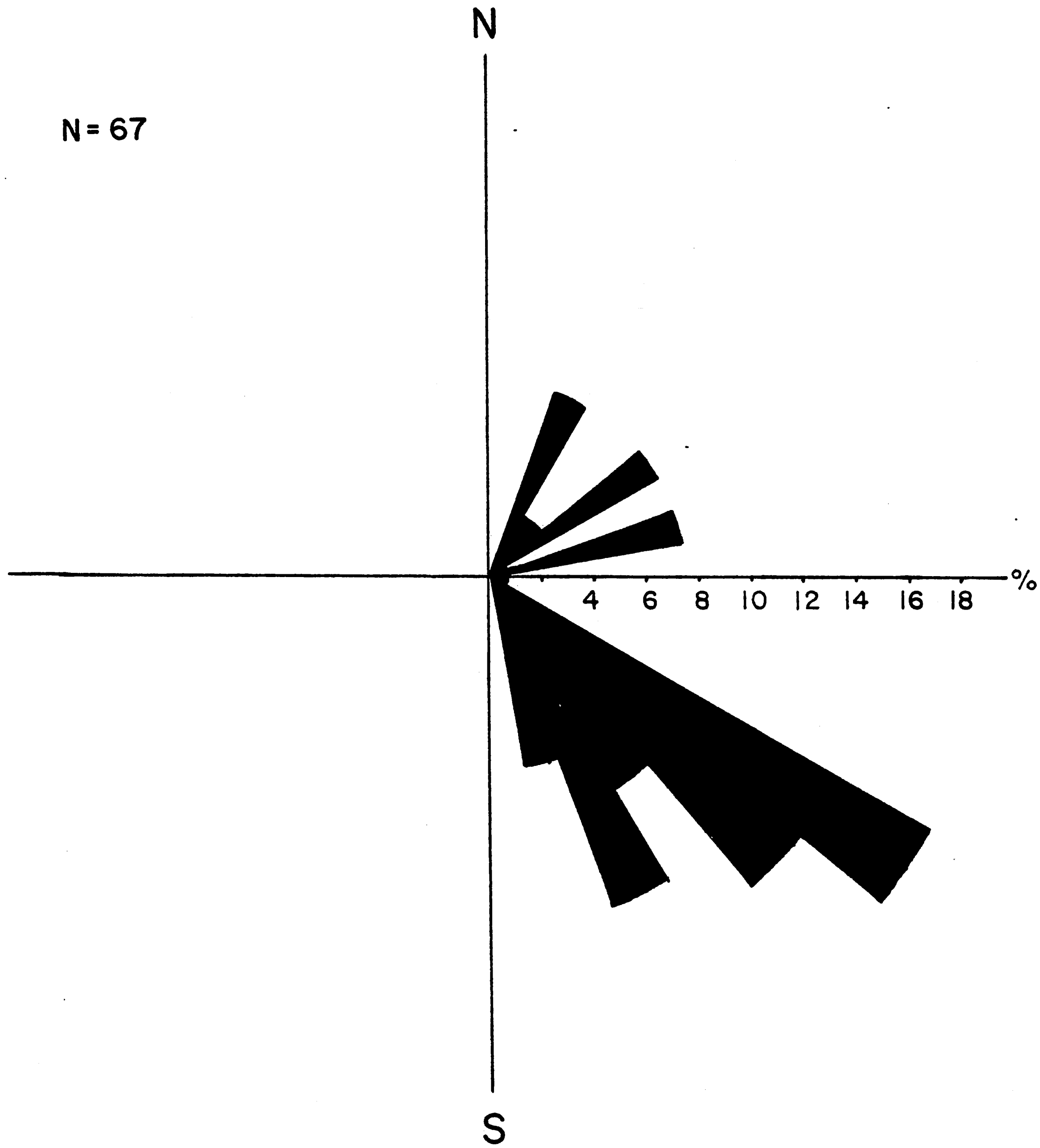

Figure 17. Rose Diagram Illustration Distribution of Joint Trends in Area of Ketch Creek; Note Percentage of Joints Between Ozimuths 020 and 030 (Data by Stubbs and Marchini, Pers. comm.)

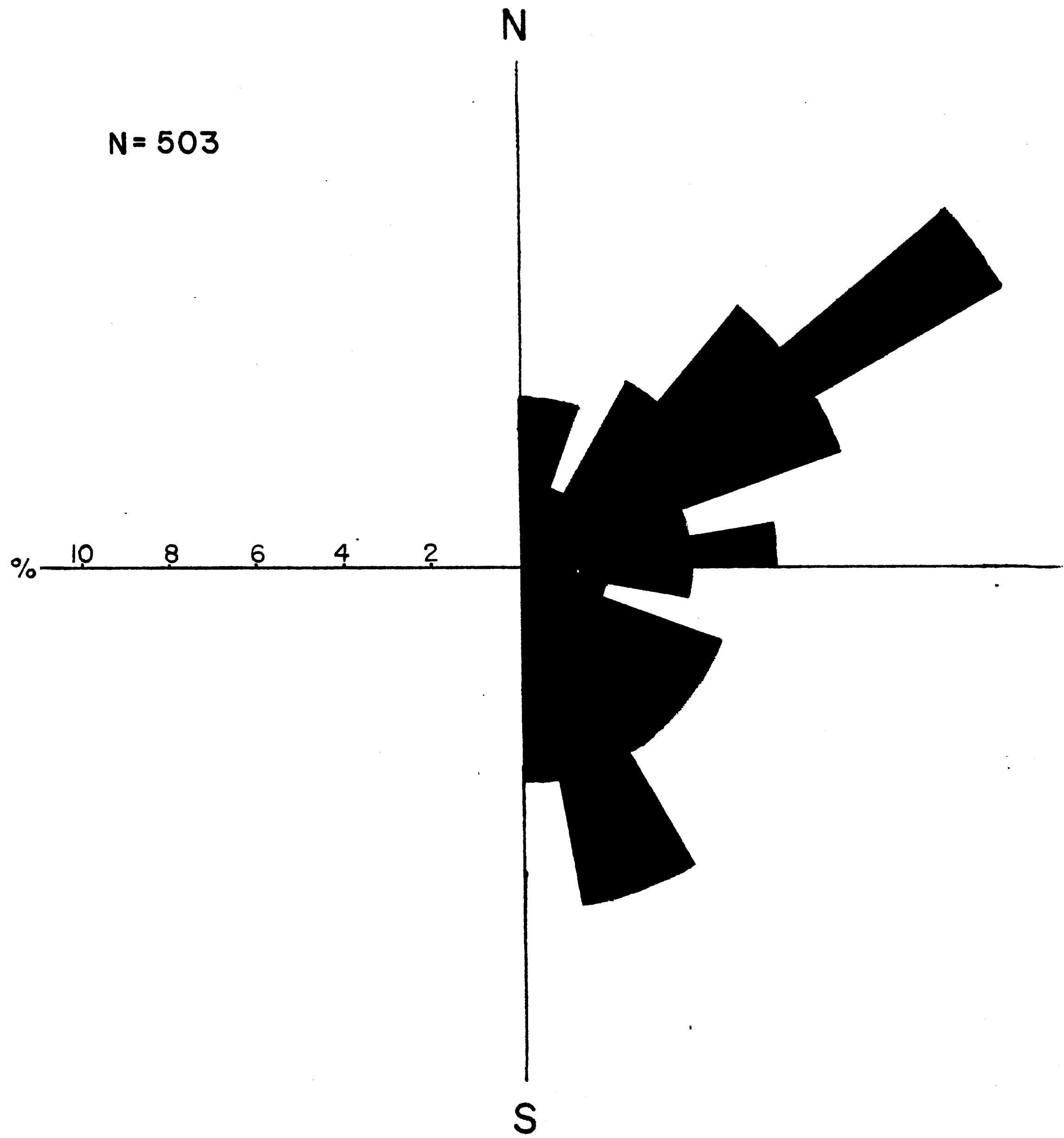

Figure 18. Rose Diagram Illustrating Distribution of Joint Trends in Area of Blue Creek Canyon Fault; Presence of Joints Between Ozimuths 000 and 020 is Decreased from Turtle Creek Fault Area

is not a major mode which can be detected in data associated with the other two major faults in the area.

It therefore seems reasonable to infer that the pronounced lineament along which Turtle Creek runs is a left-lateral slip fault, although no evidence of the amount of slip has been seen. Also, it is suggested that a set of fractures with azimuths ranging 000 to 030 is directly associated with the Turtle Creek Fault. Both the fault and its associated joint set appear to be traces of a Cambrian structural grain because the fault does not cut post-rhyolite sediments of the Timbered Hills and Arbuckle groups. This relationship can be observed in the field, as well as inferred from aerial photographs and topographic maps.

Another possible, though less distinct indicator of a Cambrian structural grain is a zone of discontinuity along a segment of the east bank of Turtle Creek, specifically: E 1/2, SW 1/4, NE 1/4, SW 1/4, SE 1/4, Sec 12, T4N R13W. The discontinuity is tentatively interpreted as a low angle (possibly thrust) fault on the basis of the following observations:

1. at one point along the east bank of Turtle Creek, a distinct plane can be seen to separate layering in the rhyolite; above the plane (which slopes upward from north to south), slightly curved, gently inclined strata are seen, whereas, below the plane, the layering is steeply inclined north to south and curves to a gentler slope as it nears the supposed fault plane (Figure 19) and
2. although the distinct cross cutting relationship occurs clearly in only one spot, the postulated fault plane can be traced 10 to 15 meters further south.

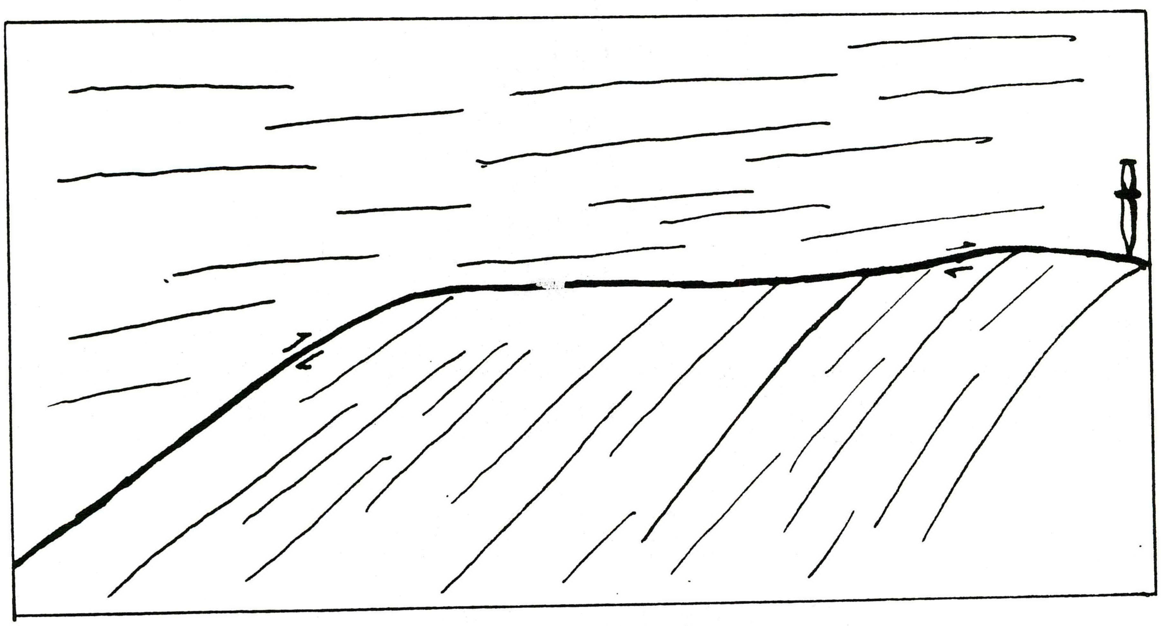

Figure 19. Photograph and Diagram Showing Relationship of Layering on Upper and Lower Sides of "Thrust Fault" Near Turtle Creek

There is possible evidence of the suggested fault on the west bank of Turtle Creek. At one point (NW 1/4, SW 1/4, NE 1/4, SW 1/4, Sec 12, T4N R13W) a subhorizontal surface can be seen separating two bodies of rhyolite. Joints in each of the bodies are discontinuous across this surface. Also, one of the bodies appears more massive, whereas the other is more highly jointed. Another possible explanation for the differences between the two bodies is that they may be parts of two different flows of rhyolite (Donovan et al., 1983). Thus, the two features described (plane of discontinuity in layering and subhorizontal surface between rhyolite bodies), though geographically close, may be totally unrelated.

Relative dating of the Turtle Creek Fault and the inferred thrust/low angle fault is comparatively simple. As the only acceptable evidence for the thrust/low angle fault exists on the east bank of Turtle Creek and is not continuous across Turtle Creek, it is inferred that the thrust/low angle fault moved earlier and was later cut by the Turtle Creek Fault with a left-lateral sense of slip.

Later (Pennsylvanian) Structural Grain

Analysis of joint orientation data from exposures of Carlton Rhyolite in Blue Creek Canyon reveals not only traces of a Cambrian structural grain, but also reveals evidence of a later structural grain. This later grain is of a stronger and more widespread character.

The age of this later grain is likely to be Pennsylvanian, as no significant periods of regional tectonism (following Cambrian tectonism) occurred until Pennsylvanian time (Donovan et al., 1983; McConnell, 1983; Gilbert, 1982). In early Pennsylvanian time, the first episode of

Pennsylvanian orogeny, termed the "Wichita Orogeny" by Ham and Wilson (1967) took place. At this time, the Wichita Mountains area was the locus of major uplift, while nearby basins were downwarped (Figure 13a). A later period of orogeny, termed the "Arbuckle Orogeny" by Ham and Wilson (1967), intensified previous deformation. It is probable that it is in these episodes of orogeny that the later structural grain has its origins.

In terms of joints, the later structural grain manifests itself (in Blue Creek Canyon) as two or three principle joint sets which are thought to be elements of a single system (Figure 20; Plate 4). The first set (B.C.C. 3), which is at low angles to the Blue Creek Canyon Fault, has a general trend of azimuth 145. These joints, where slip can be detected, usually record left-lateral movement. The second set, (B.C.C. 2), which is less prominent that the first, has a general trend of azimuth 075. In limestones stratigraphically above the rhyolite, faults of similar trend with right-lateral slip have been observed (Stubbs, 1984). It is assumed that since the right-lateral slip faults have similar orientations to the second set (B.C.C. 2) of described joints, as well as having their genesis in the same orogenic episodes, they are different manifestations of a similar structural grain. A similar assumption is made concerning the first set (B.C.C. 3) and the Blue Creek Canyon Fault. As mentioned earlier, a probable third set of joints (B.C.C. 1) exists. This set has a general trend of azimuth 035. It is tentatively inferred that the three described sets of joints (B.C.C. 3, B.C.C. 2, and B.C.C. 1) are parts of a larger, particular type of joint system (the significance of B.C.C. 1 can be seen later in this paper).

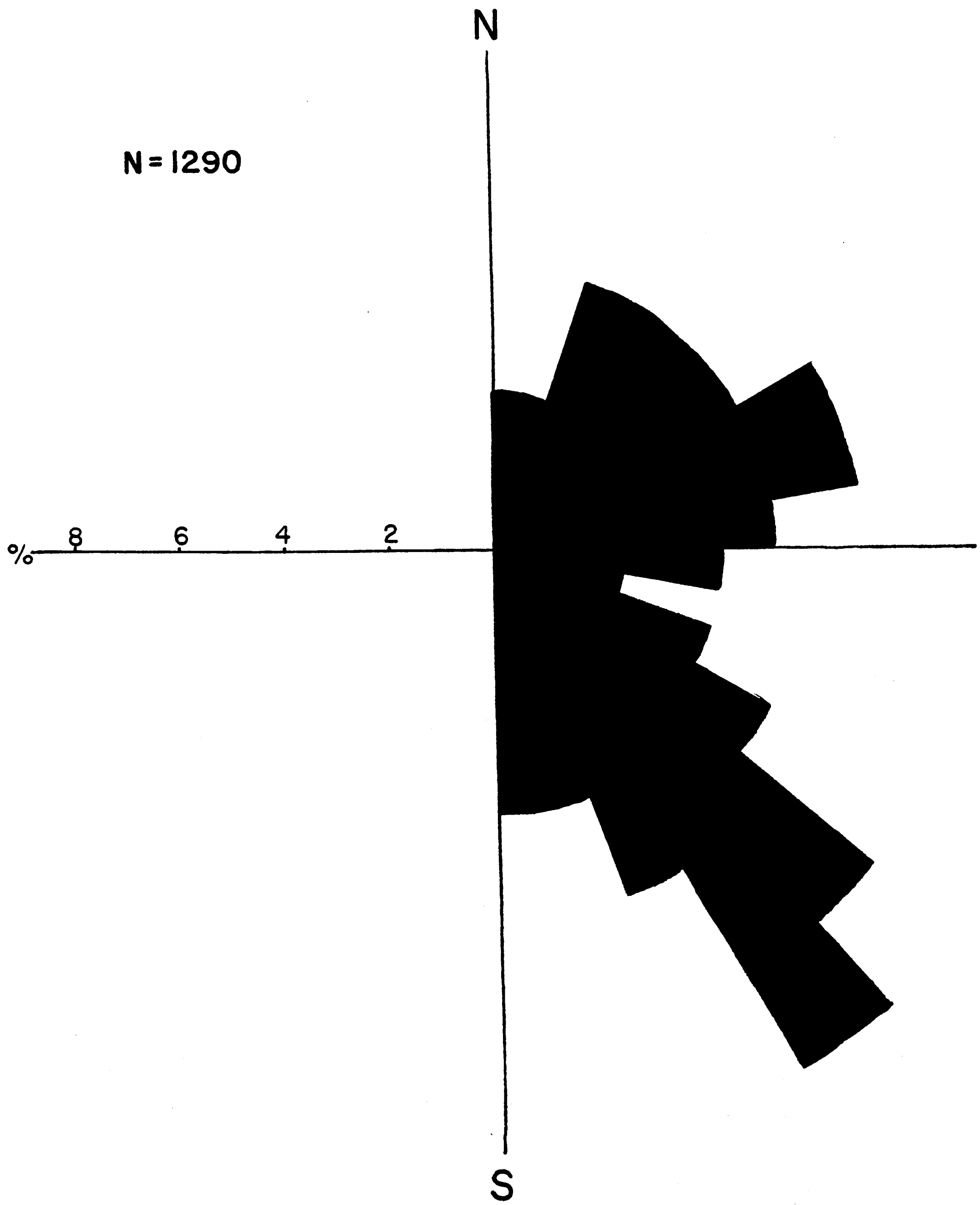

Figure 20. Rose Diagram Illustrating Principle Joint Sets as Part of Later Structural Grain in Blue Creek Canyon

It can be deduced from Figure 21 that the maximum compressive stress bisects the angle between two principle planes of slip (B.C.C. 2, and B.C.C. 3 in this case). Therefore, the maximum compessive stress (at least locally) was oriented with a trend of roughly 110. Based on analysis of folds to the west of Blue Creek Canyon, Donovan (1982) has suggested that a similar stress was operative during movement of the Blue Creek Canyon Fault.

Tectonic Folding in Rhyolite
East of State Highway 58

Examination of layering (sheeting) orientations in the rhyolite exposed in Blue Creek Canyon has revealed the presence of tectonic folding (Plate 3). Upon first examination, it may seem that many such folds exist, but close examination reveals that the folding is really a single anticline, which trends approximately 340, and plunges northwestward. The anticline's features are distorted by flow folds existing in the rhyolite prior to the tectonic folding. The flow folds are numerous and widespread. Flow folds are herein classified as folds which exhibit none of the jointing patterns classically believed to be associated with tectonic folding (e.g., shear joints, extension joints).

Correlation of Local and Regional Development

The Cambrian tectonism which caused the Turtle Creek Fault and its associated joint set may possibly be related to, or be a part of, the tectonism that caused faulting which caused truncation of an inferred Proterozoic (Pre-Cambrian) basin said to lie under the present Hollis/Hardeman Basin (Brewer et al., 1981). Brewer et al. (1981) also stated

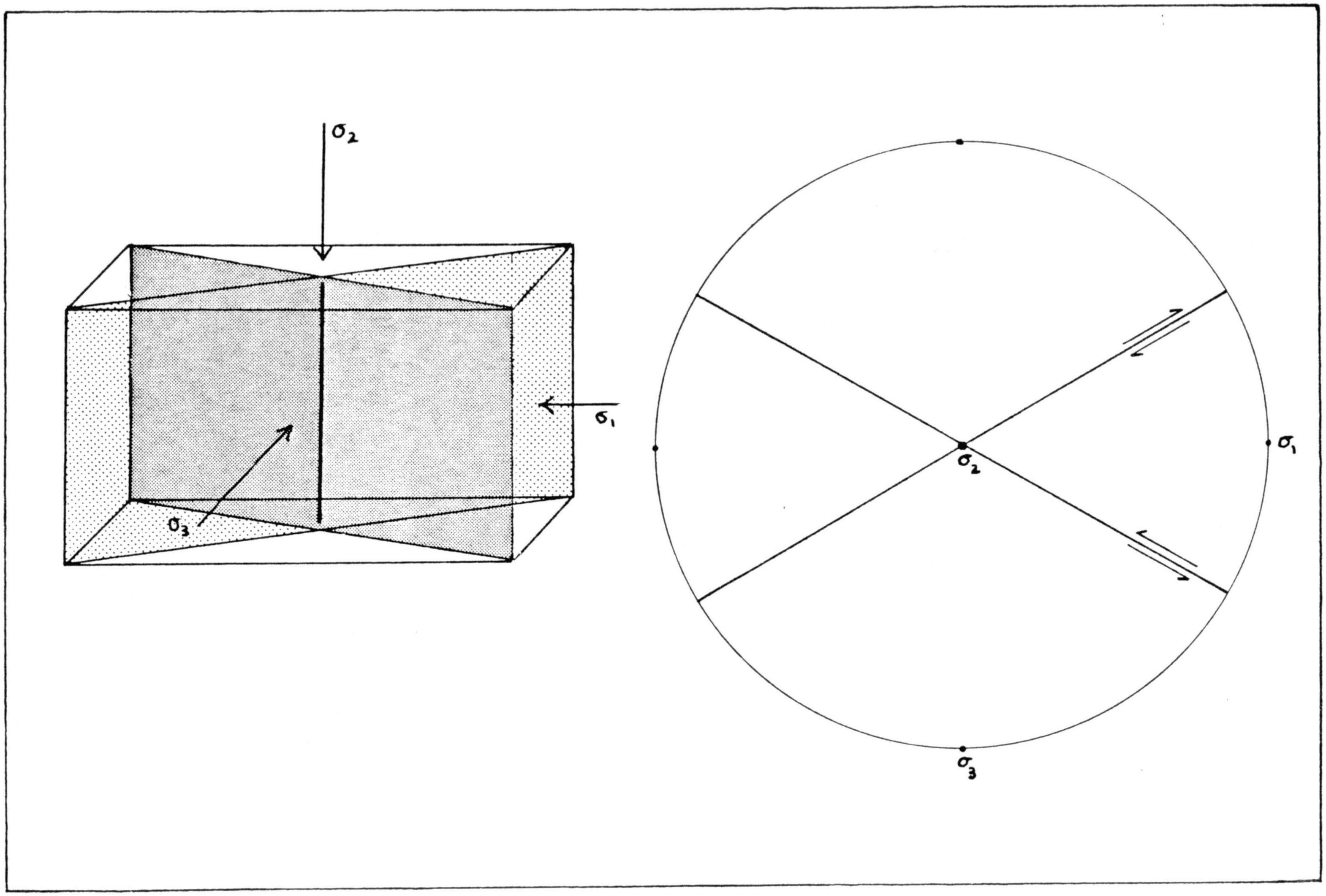

Figure 21. Diagram Illustrating Right-lateral and Left-lateral Slip in a Conjugate System of Transcurrent Faulting

that truncation of the inferred Proterozoic layered rocks must have been pre-late Cambrian (pre-Reagan Sandstone), as rocks of this age overlie the Burch Fault with only moderate offset due to Pennsylvanian activity. Brewer et al. (1981) further stated that crustal extension during the pre-Cambrian period is suggested by rhyolitic, granitic, and diabasic dikes which approximately parallel the trend of the aulacogen.

The inferred later (Pennsylvanian) structural grain (Plate 4) is part of, or related to, crustal shortening at that time. The crustal shortening was due to collision of the North American plate with an inferred island arc or continent, to the south. It was during the crustal shortening that the Wichita Mountains region became an area of major uplift. Brewer et al. (1981), stated that existing pre-Cambrian trends were reactivated during the Pennsylvanian activity. Left-lateral wrench faulting (later in the Pennsylvanian) which occurred in the Wichitas, may have been due to thrusting of the Ouachitas against the foreland (Donovan, 1982).

Discussion

Of great importance to this study is the inference of a structural trend (grain) that is syn- or post-rhyolite and pre-Reagan Sandstone in age. This trend is indicated by a fault (Turtle Creek Fault) observed in the Blue Creek Canyon area. The fault trends north-south, and its nature is suggested by:

1. the unusually straight trace of Turtle Creek, as observed from aerial photography and topographic maps;
2. a number of sharply defined, straight, smooth joints which parallel the creek's trend; and

3. quartz-filled veins, oriented in such a way that a left-lateral sense of shear across Turtle Creek is indicated.

Further evidence to suggest post-rhyolite, pre-Reagan tectonism is furnished by Donovan and Gilbert (1985), who stated that:

1. mapping of the Blue Creek Canyon area shows a slight (c. 5°) dip on the Carlton Rhyolite prior to deposition of the Reagan Sandstone and
2. there are several dikes of syn- or post-rhyolite, pre-Reagan age that trend 300-320 (approximately parallel to the trend of the aulacogen), suggesting crustal extension at this time.

A noteworthy aspect of this structural grian is its possible influence on later structures. One distinct possibility of this occurrence is seen in the anomalous trend of the Blue Creek Canyon Fault. The Blue Creek Canyon Fault, of Pennsylvanian age, is commonly thought to have a trend of about 310 (e.g., Havens, 1977), both north and south of Blue Creek Canyon. In Blue Creek Canyon, this trend anomalously changes to approximately 360 (north-south) (Plate 4). It seems possible that this abrupt change in trend could be due to a pre-existing structural grain in the area. This possibility was also suggested as a "wild card" by Donovan (1982).

The later (Pennsylvanian) structural grain, noted in Blue Creek Canyon, is interpreted to be a manifestation of jointing associated with left-lateral wrench faulting. The data for Blue Creek Canyon, when compared to that from the Bally Mountain/Zodletone Mountain area, and data from the Wichita Granites (McLean, 1983), define regional modes of jointing (Figures 22 and 23) which are interpreted here as Riedel,

Predominant Joint Trends	McLean (Ꞓwg)	Hester (Ꞓcr)					
		air photos/grid system		field work			
		B.C.C.	Bally Mtn.	B.C.C./all data	Turtle Creek zone	B.C.C.F. zone	K.C.F. zone
	025	030—040		030—040	010—020	005—015	020—030
	075	085—095	060—070	070—080	085—095	050—060	050—060
	095	110—120	090—100			080—090	070—080
	115	140—150	140—150	140—150	140—150	155—165	120—130
	180	170—180	160—170		160—170		150—160

Figure 22. Comparison of Predominant Lineament/Joint Trends in Wichita Granites (McLean) and Carlton Rhyolite (Heater): B.C.C. = Blue Creek Canyon; B.C.C.F. = Blue Creek Canyon Fault; K.C.F. = Ketch Creek Fault

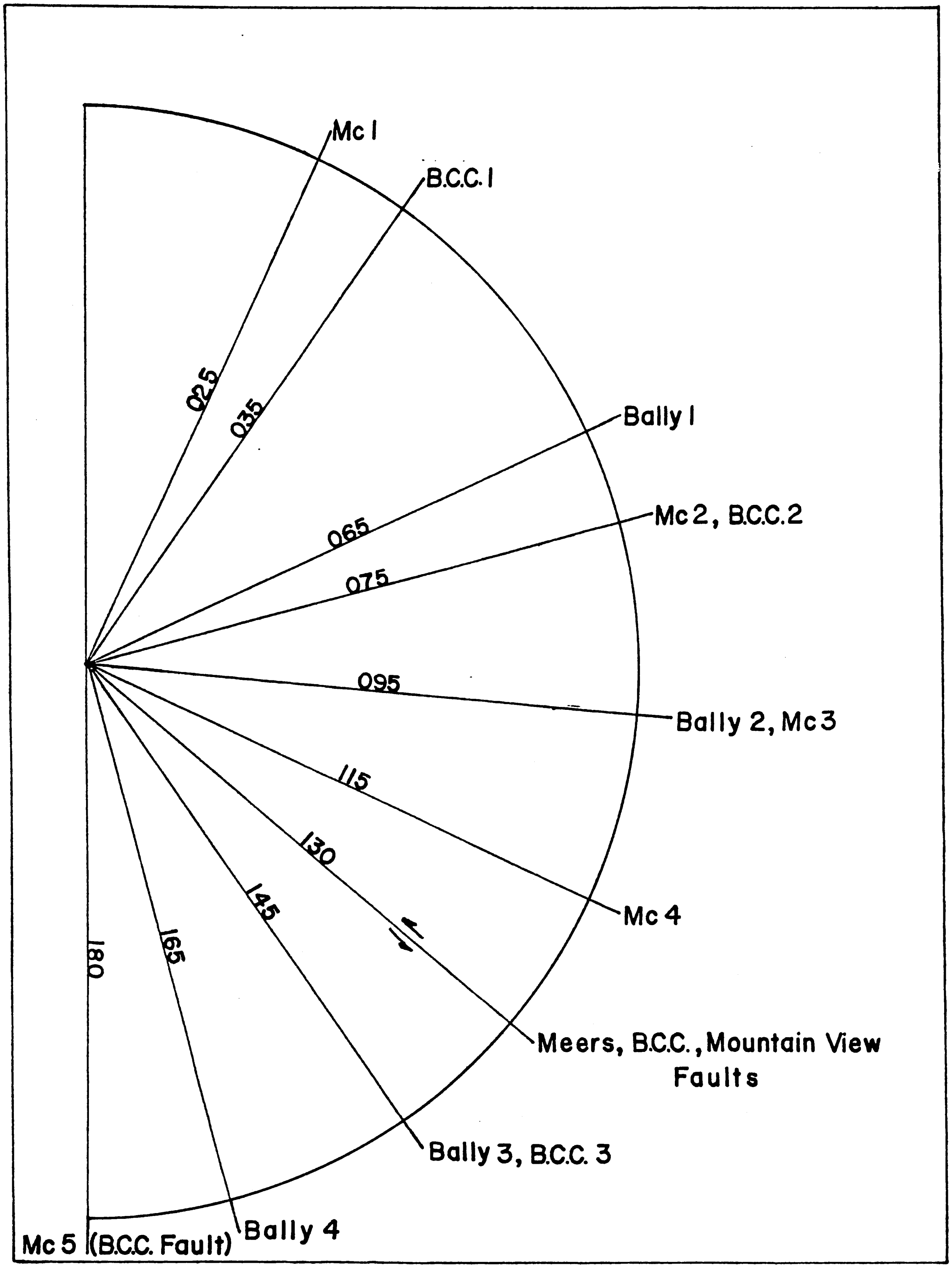

Figure 23. Trend Diagram of Major Faults and Lineaments/Joints: Mc = McLean; B.C.C = Blue Creek Canyon; Bally = Bally Mt.

conjugate Riedel, P-, and X-shears (Figure 24). With this interpretation, the maximum compressive stress would have been oriented with a trend of about 085. This is in contrast to the work of McLean (1983) which, although it interprets jointing and faulting in the Wichita Granites as being representative of the same type of system, implies a maximum compressive stress with a trend of about 050. This seems inconsistent with his (McLean's) discussion of (probable) wrench faulting in the region, specifically the orientation and sense of slip along major faults in the area (Meers, Blue Creek Canyon, and Mountain View Faults), if these faults are taken as being wrench faults, or as oblique faults with considerable lateral slip.

Tectonic folding in the Blue Creek Canyon area is apparently limited to a single plunging anticline. Numerous, widespread, small scale folds exist in the exposures of Carlton Rhyolite that were studied. These small structures are interpreted as flow folds. The pre-existing flow folds distort and disguise the tectonic fold in the field, but their influence is far less apparent when sheeting orientations are analyzed over the region as a whole (Plate 3) .

Summary and Conclusions

In this study, the following inferences are made:

1. there is a previous (Cambrian) structural grain in the area studied. Points of evidence suggesting this grain are: (a) an inferred fault within the Carlton Rhyolite (in Blue Creek Canyon) which fails to cut overyling sediments; (b) a suggestion made by Donovan and Gilbert (1985) (based upon ongoing field observations) stating that a slight (c. 5°) structural

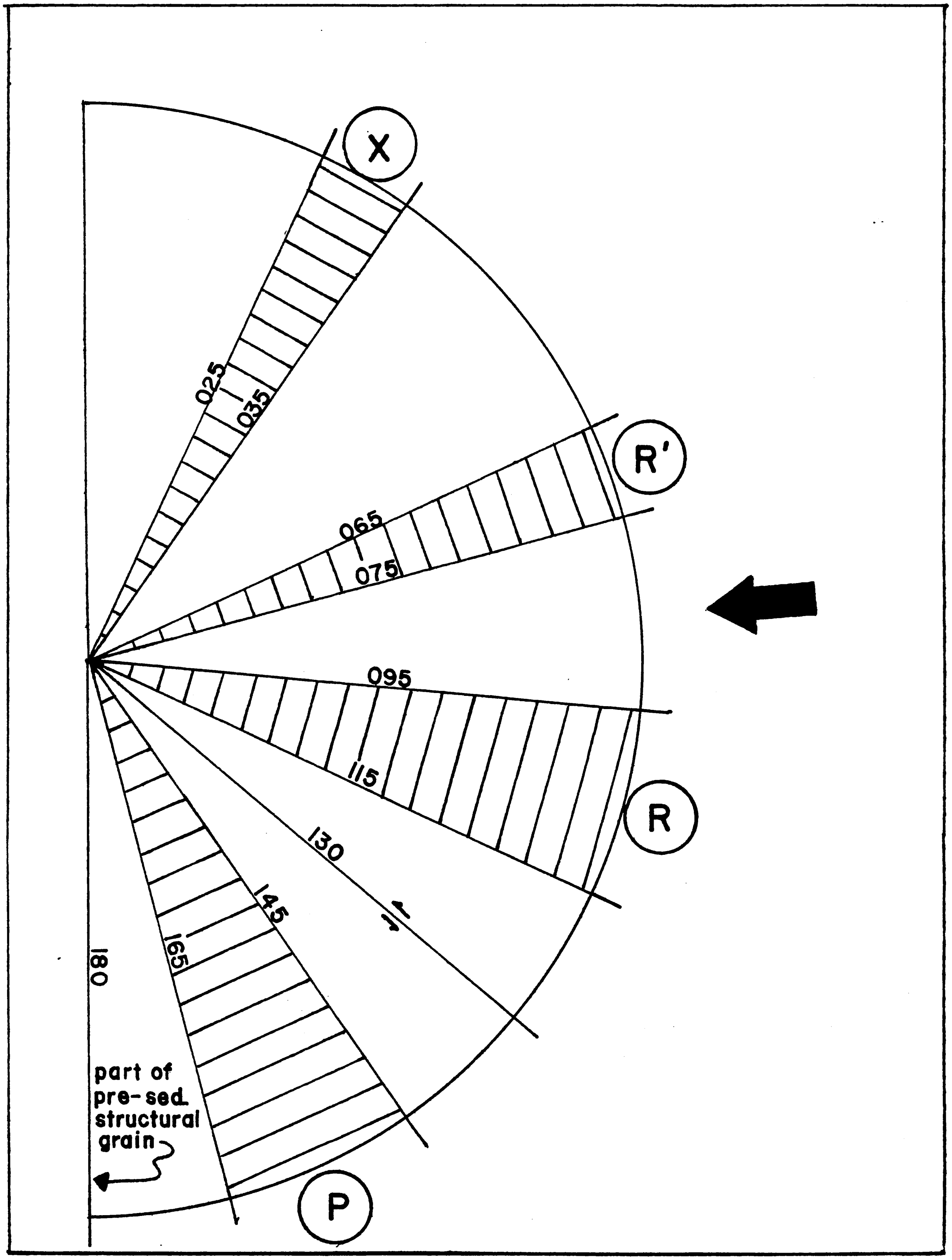

Figure 24. Diagram Showing Interpretation of Data from Figure 24; Arrow Indicates Direction of Maximum Compressive Stress

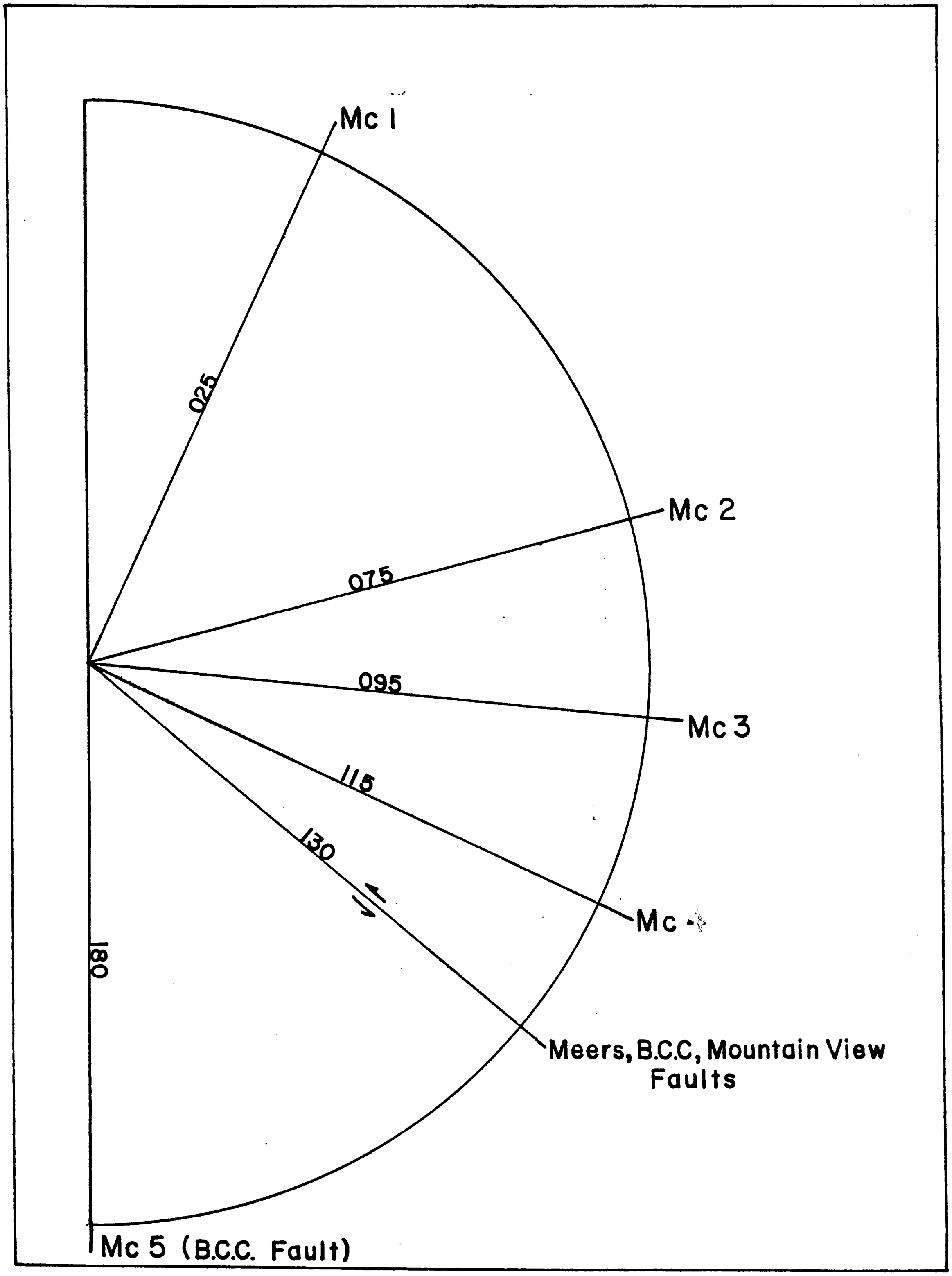

Figure 25. Trend Diagram of Data by McLean (1983)

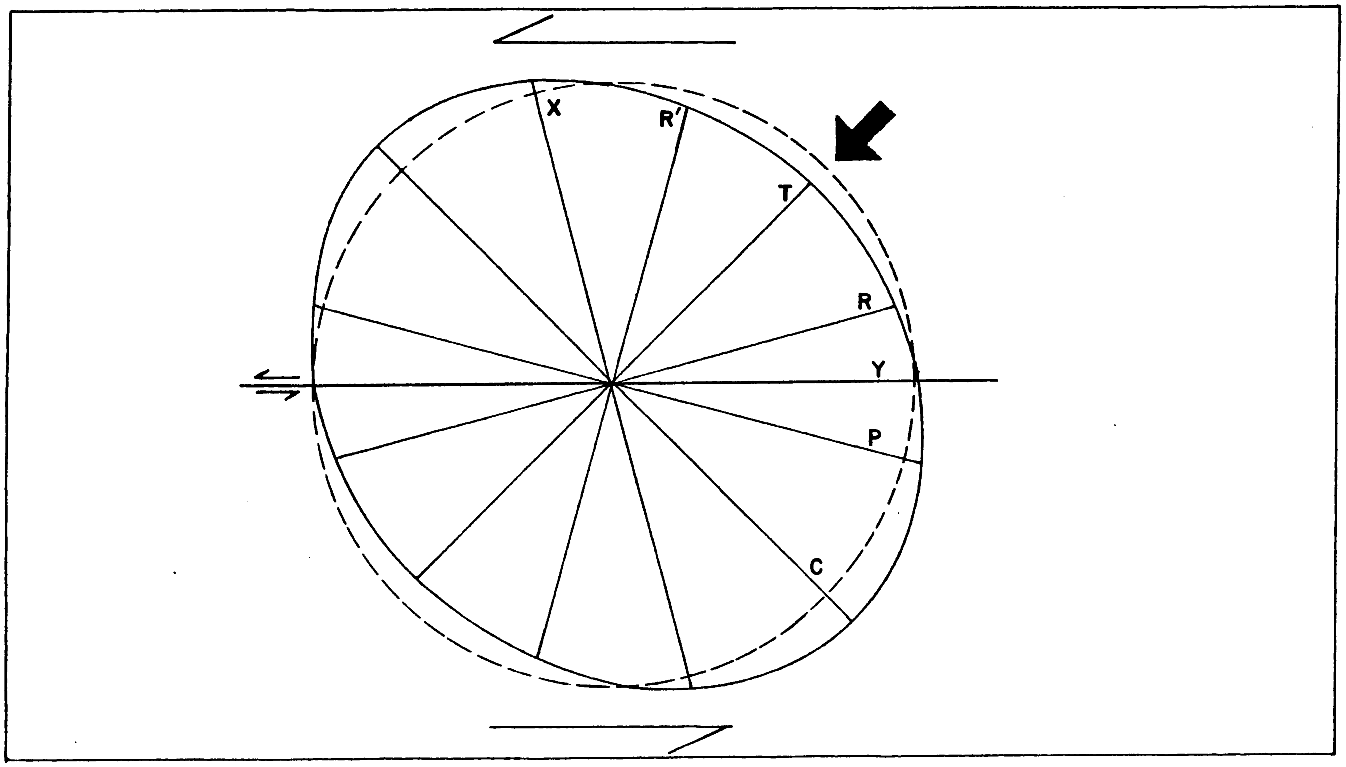

Figure 26. Diagram of Possible Features in a Left-Lateral Wrench Fault/Zone: R = Riedel Shears; R' = Conjugate Riedel Shears; P = P-shears; X = X-shears; Y = Shears Parallel to Main Wrench Fault; T = Tensional Features; C = Compressional Features; Arrow Indicates Direction of Maximum Compression (Adapted from Bartlett et al., 1981)

dip on the Carlton Rhyolite existed prior to deposition of the Reagan Sandstone; and (c) dikes that parallel (roughly) the aulacogen and do not cut post-rhyolite sediments, implying crustal extension (Donovan and Gilbert, 1985);

2. there is a later (Pennsylvanian) structural grain which manifests itself chiefly as a series of faults and joints/lineaments which are interpreted to be R- (Riedel), R-' (Conjugate Riedel), P- and X-shears associated with left-lateral wrenching. From the orientations of these features, it is inferred that the maximum compressive stress was oriented approximately at 085; and
3. confirmation that a single tectonic fold exists in the rhyolite exposed in Blue Creek Canyon. This fold has previously been suggested by others (e.g., Donovan, 1982). The appearance of the tectonic fold is disguised by numerous, widespread flow folds.

CHAPTER V

SUMMARY, CONCLUSIONS, AND SUGGESTIONS FOR FURTHER STUDY

Summary and Conclusions

The Wichita Mountains record local Pennsylvanian reactivation of elements of the Southern Oklahoma Aulacogen. During its formation, the aulacogen (which probably overlies an earlier Proterozoic basin) underwent two basic igneous events, followed by a granitic/rhyolitic event, and lastly a third basic event. During the granitic/rhyolitic event, the Carlton Rhyolite Group was extruded chiefly as a series of flows and tuffs; Pyroclastic agglomerates also accumulated. Laterally, the rhyolite covers an area of about 17,000 square miles. Maximum known thickness of the rhyolite is 4,500 feet. Principle exposures of the rhyolite occur in the Wichita Mountains and Arbuckle Mountains. The upper and lower surfaces of the rhyolite are marked by unconformities.

Following igneous activity, slow subsidence and deposition occurred until Pennsylvanian time, when orogeny caused formation of the Wichita and Arbuckle Mountains. Up to 9 km of Pennsylvanian and Permian sedimentation occurred in coeval basins adjacent to the mountains. Erosion has revealed the Wichitas' topography as an exhumed land surface upon which Pennsylvanian and Permian sediments can be seen to lap.

In this study of the fracture and flow characteristics of the Carlton Rhyolite, three main inferences are made:

1. a previous (Cambrian) structural grain exists in the study area; it is suggested by: an inferred fault that cuts the rhyolite, but not overlying sediments; a suggestion by Donovan and Gilbert (1985) stating that a slight (c. 5°) structural dip existed on the rhyolite prior to deposition of the Reagan Sandstone; a further suggestion by Donovan and Gilbert (1985) stating that some dikes are sub-parallel to the aulacogen, and do not cut post-rhyolite sediments, implying pre-sediment crustal extension;
2. there is a later (Pennsylvanian) structural grain, seen as a series of joints/lineaments and faults, which are interpreted to be R-, R'-, P-, and X-shears associated with left lateral wrenching. Due to the orientations of these features, it is inferred that the maximum compressive stress was oriented approximately at 085; and
3. confirmation of a single tectonic fold that exists in the rhyolite that is exposed in Blue Creek Canyon. This fold has previously been suggested by others (e.g., Donovan, 1982). The appearance of the tectonic fold is disguised by numerous, widespread flow folds.

Suggestions for Further Study

There are three principle suggestions for further study of topics covered in this study:

1. a search for further evidence either confirming or disproving the inferred Cambrian structural grain. This search should, as far as possible, extend to aspects

beyond study of surface lineaments in the Carlton Rhyolite and Wichita Granites;

2. a more intensive search for pre-sediment dikes should be carried out to more accurately determine a regional extension direction; and

3. a more detailed study should be made of flow orientation of the rhyolite, in order to more accurately determine the direction from which the rhyolite flowed.

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Turtle Creek Fault Zone

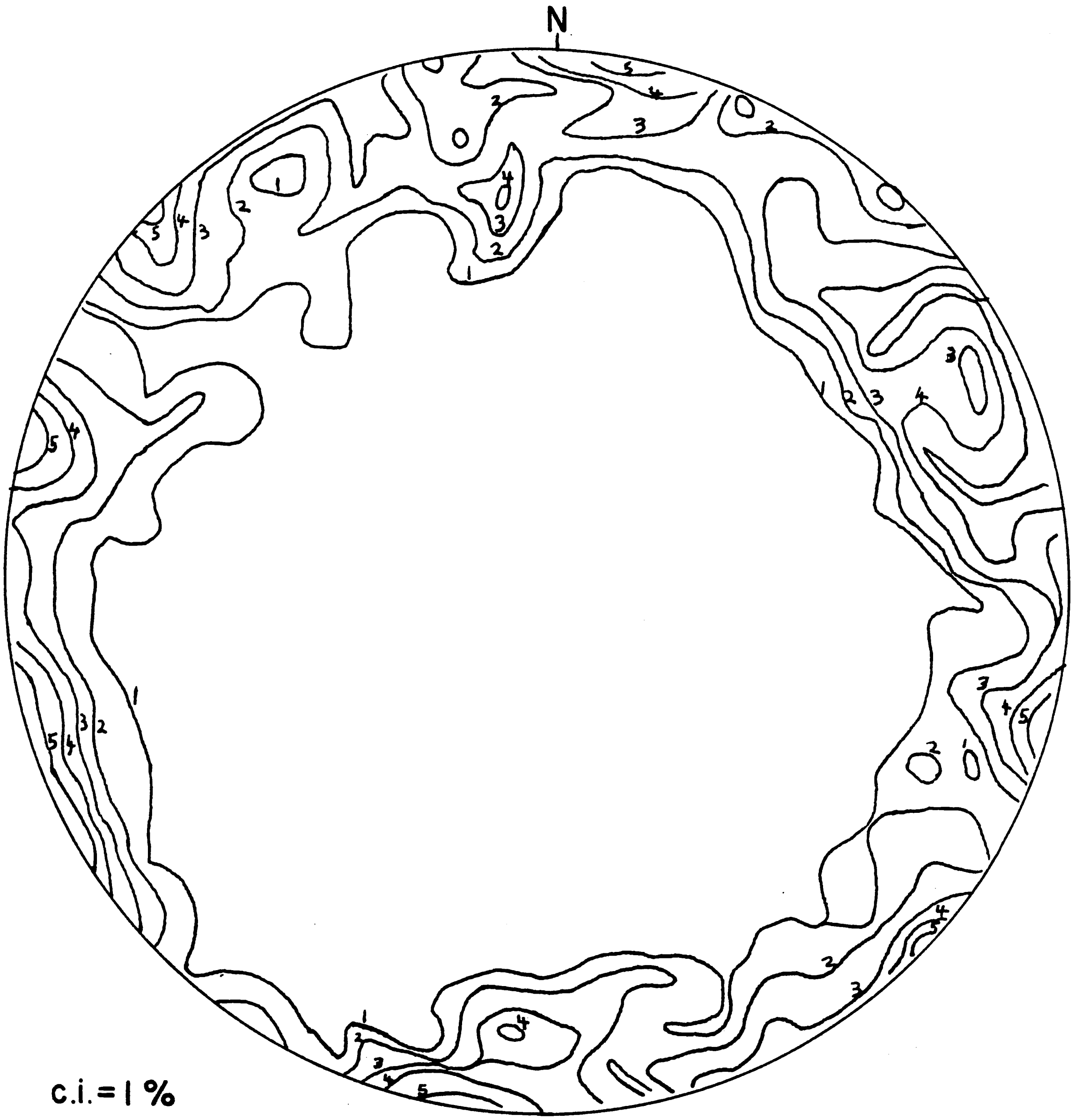

Figure 27. Contour Diagram for Poles to Joints in Turtle Creek Area

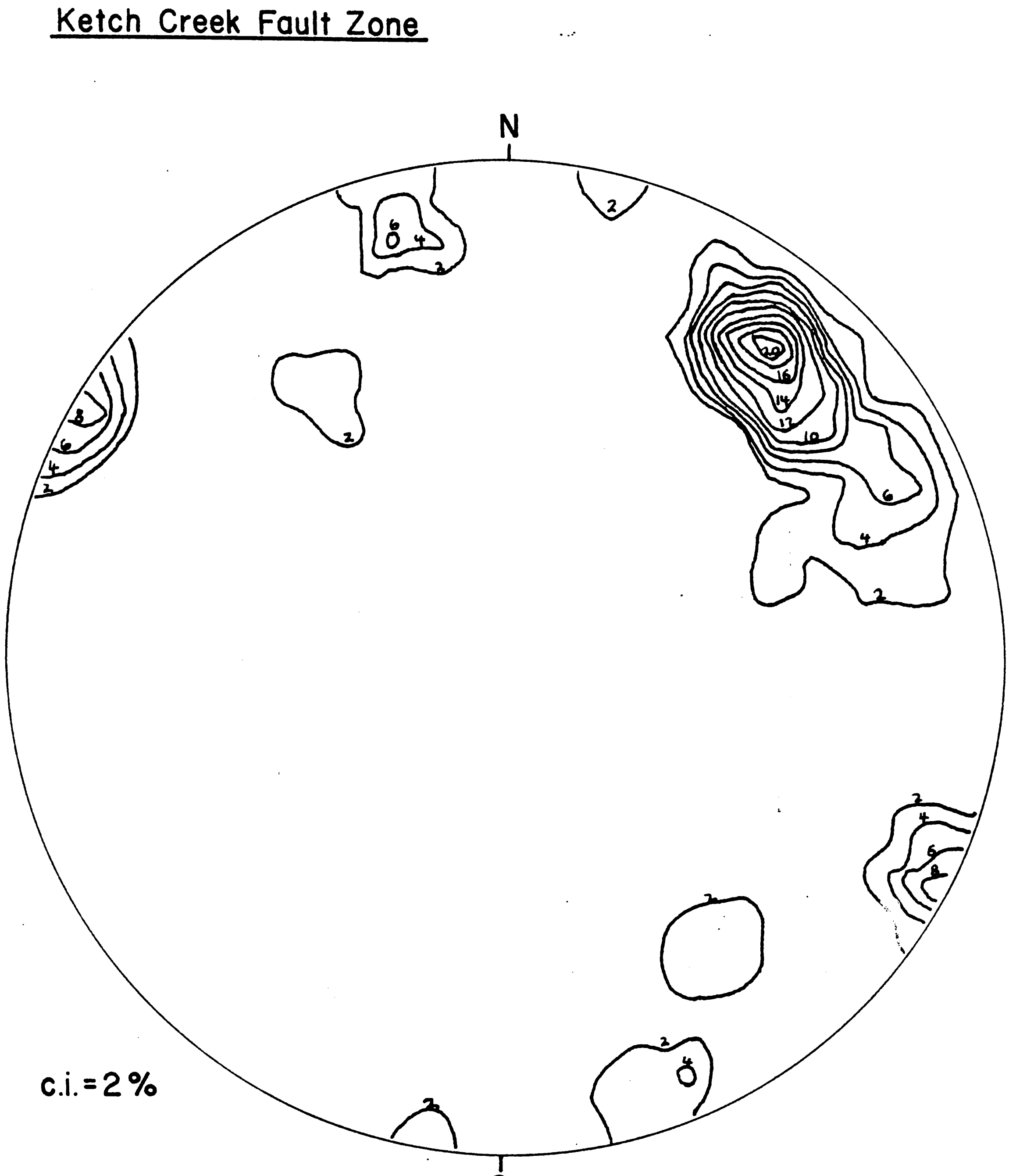

Figure 28. Contour Diagram for Poles to Joints in Ketch Creek Fault Area

B.C.C. Fault Zone

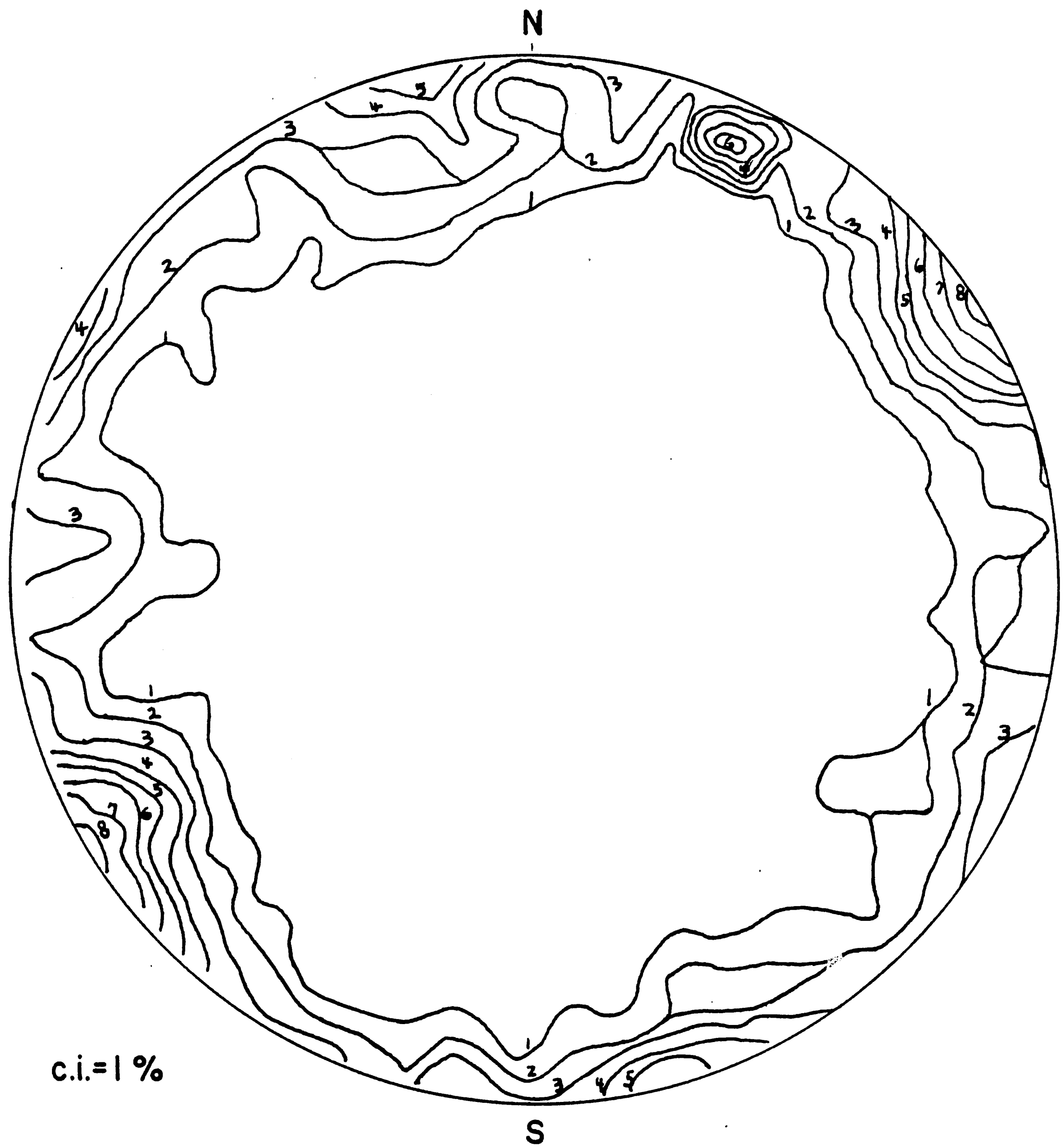

Figure 29. Contour Diagram for Poles to Joints in Blue Creek Canyon Fault Zone

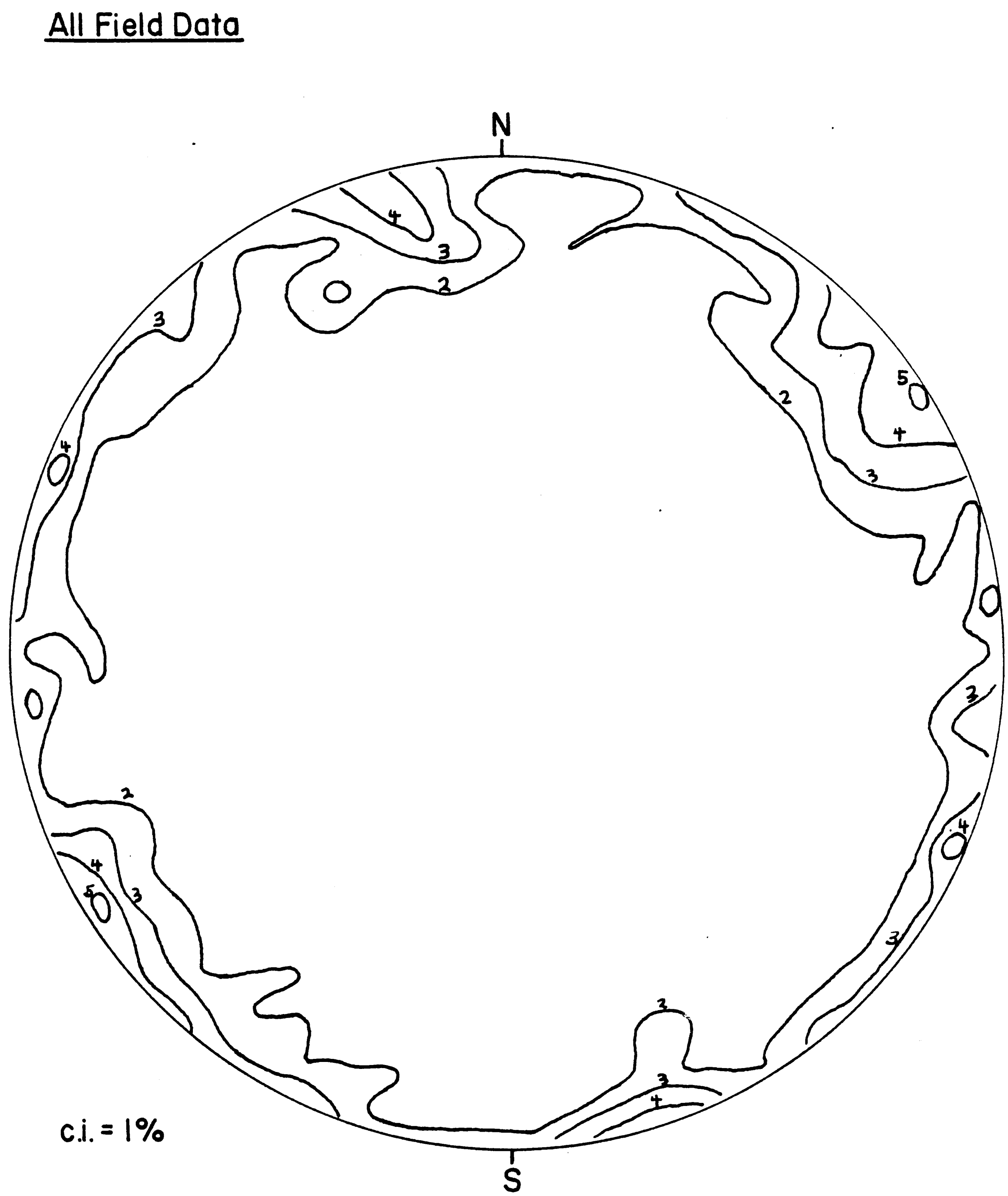

Figure 30. Contour Diagram for Poles to All Joints in Study Area

VITA

William Christopher Hester

Candidate for the Degree of

Master of Science

Thesis: FRACTURE PATTERNS AND FLOW ORIENTATION IN THE CARLTON RHYOLITE WICHITA MOUNTAINS AREA, SOUTHWEST OKLAHOMA

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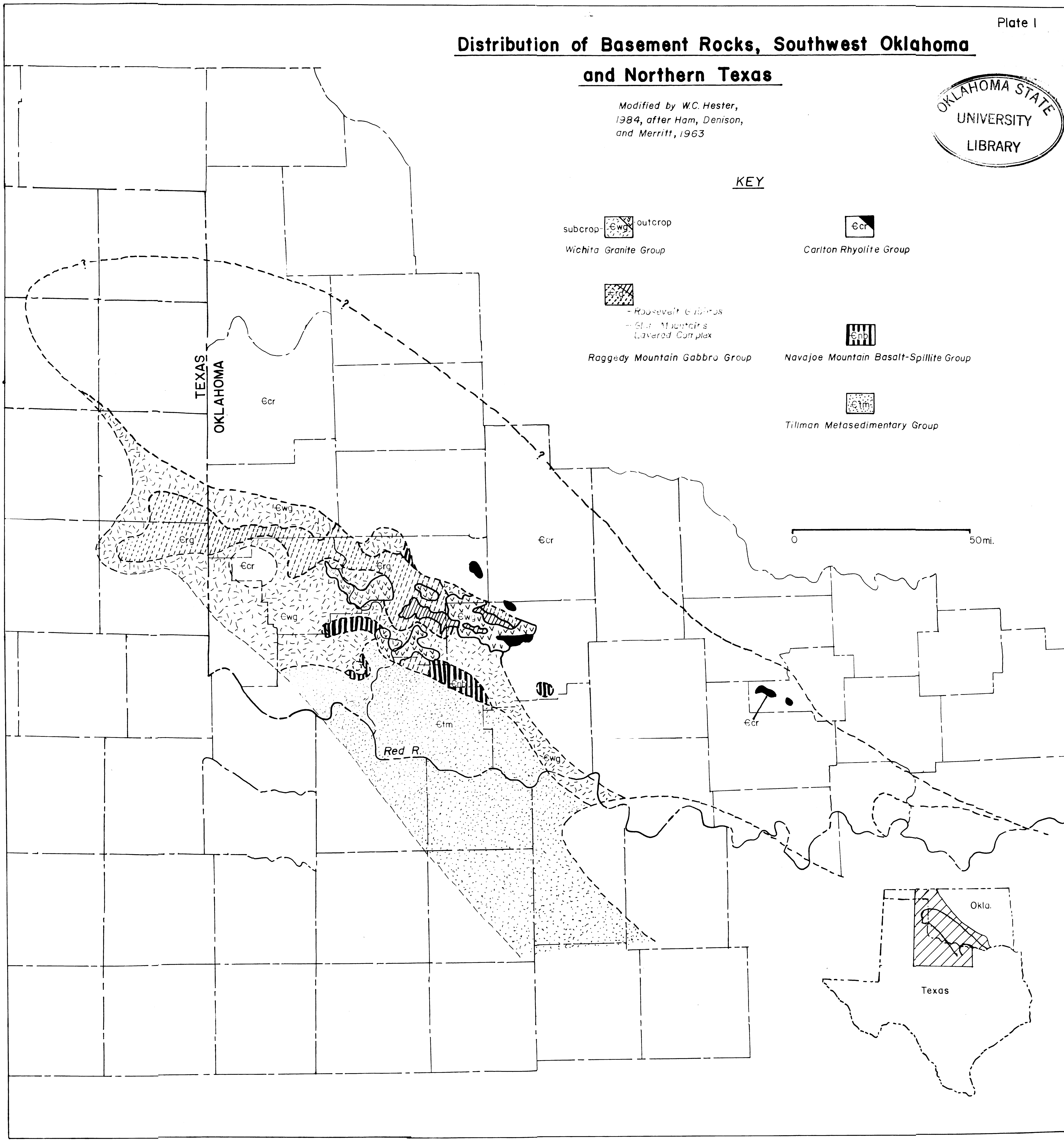


Plate I
Distribution of Basement Rocks, Southwest Oklahoma and Northern Texas
Modified by W.C. Hester, 1984, after Ham, Denison, and Merritt, 1963
KEY
subcrop
€wg
outcrop
Wichita Granite Group
€cr
Carlton Rhyolite Group
€rg
Raggedy Mountain Gabbro Group
€nb
Navajoe Mountain Basalt-Spillite Group
€tm
Tillman Metasedimentary Group
TEXAS
OKLAHOMA
€cr
€wg
€rg
€cr
€rg
€wg
€wg
€nb
€tm
Red R.
€wg
€cr
€cr
0
50mi.
Okla.
Texas

Plate 2

Fracture Pattern/Flow Line Orientation

W.C. Hester, 1984

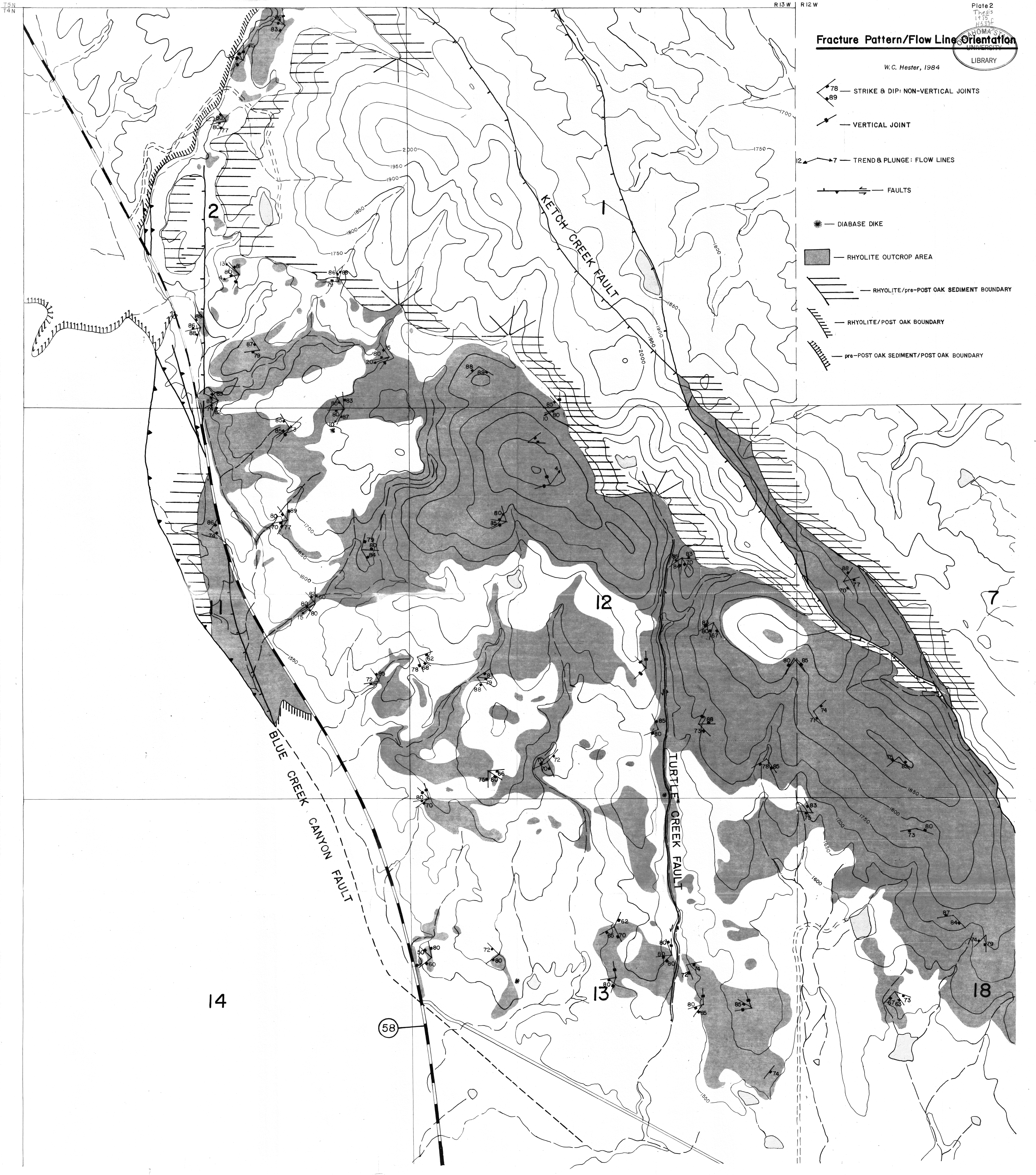


Plate 3

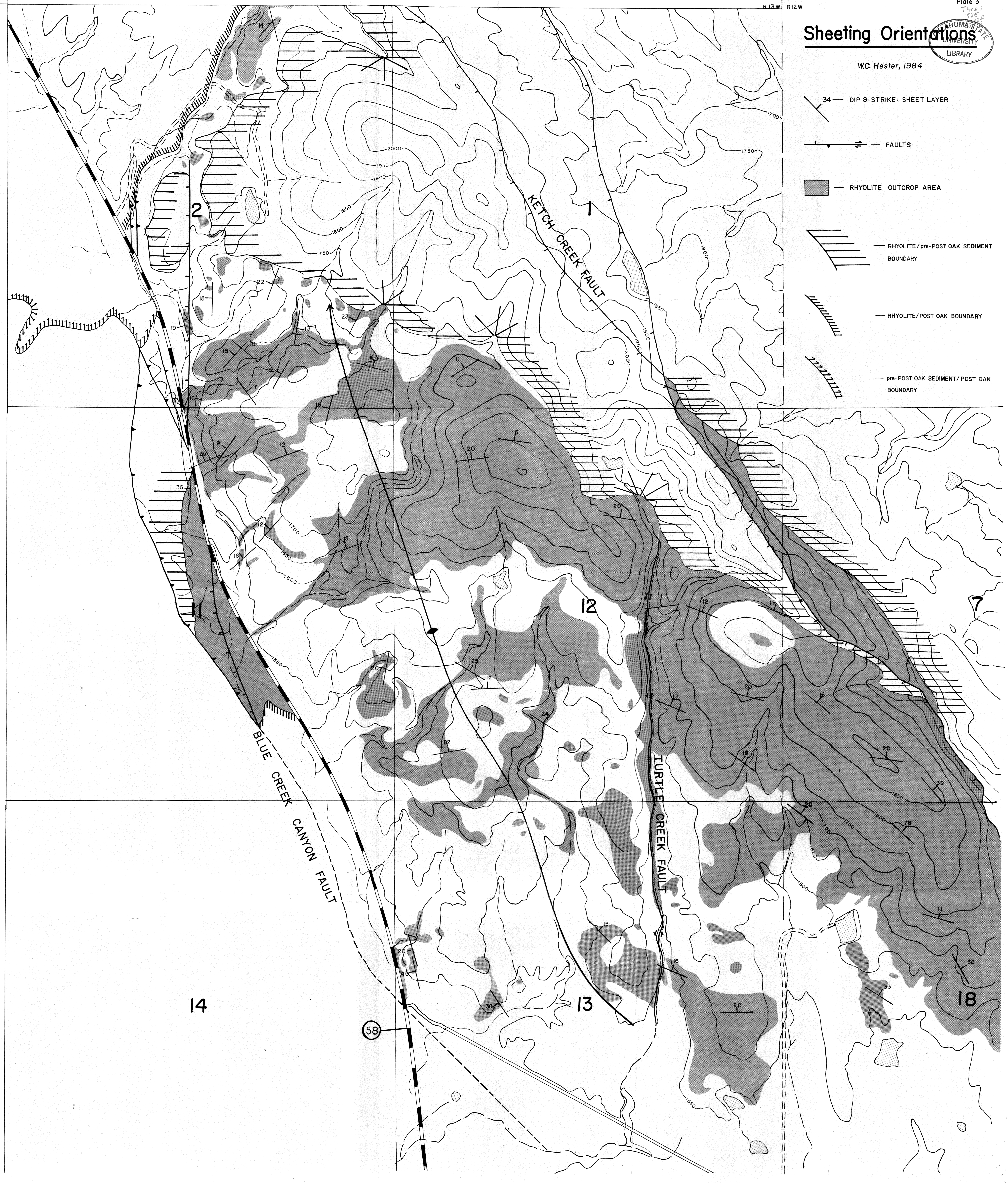
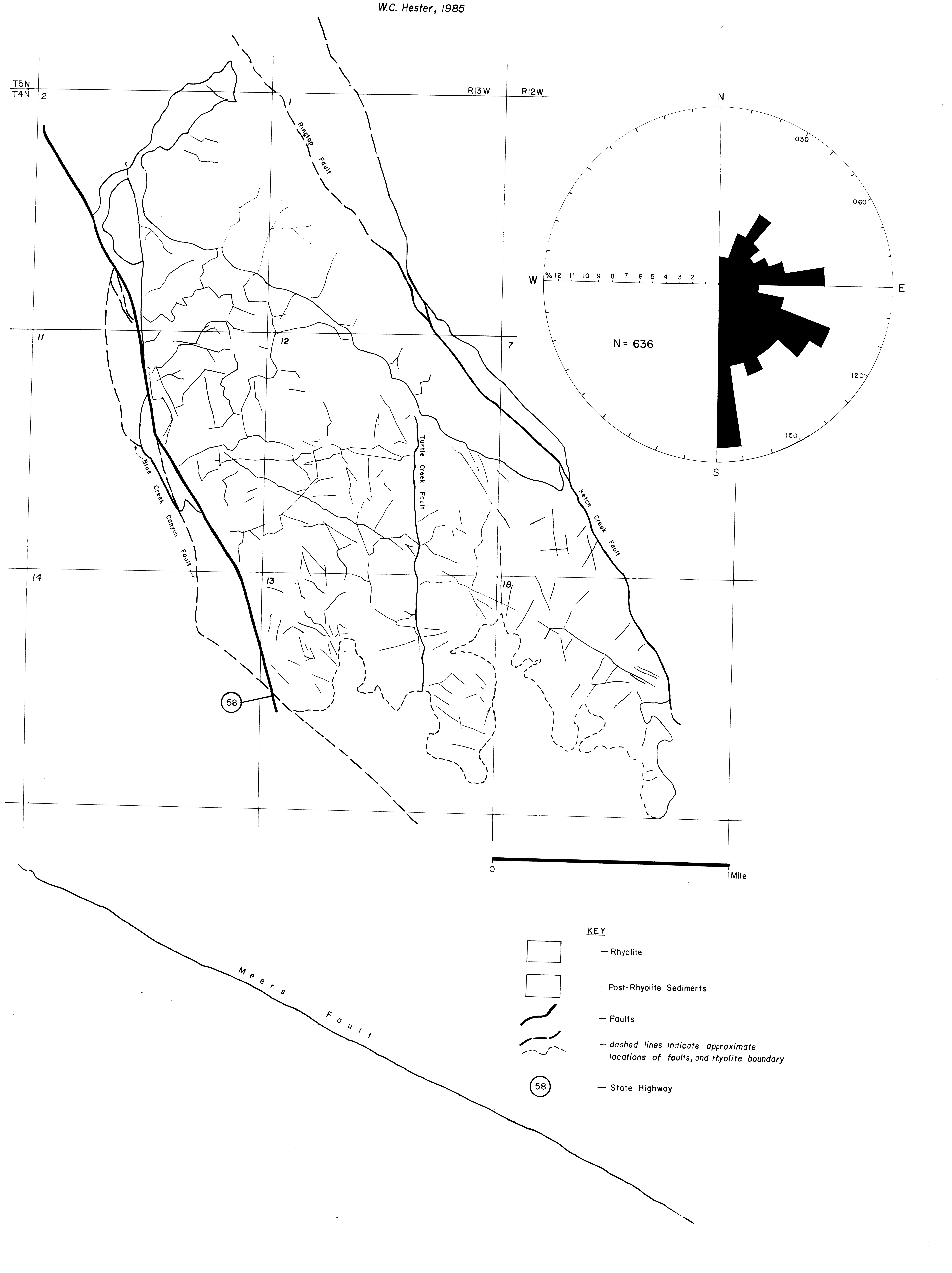

Sheeting Orientations
W.C. Hester, 1984
34 — DIP & STRIKE: SHEET LAYER
— FAULTS
— RHYOLITE OUTCROP AREA
— RHYOLITE / pre-POST OAK SEDIMENT BOUNDARY
— RHYOLITE/POST OAK BOUNDARY
— pre-POST OAK SEDIMENT/ POST OAK BOUNDARY
T5N
T4N
R13W
R12W
KETCH CREEK FAULT
TURTLE CREEK FAULT
BLUE CREEK CANYON FAULT
58

Plate 4

Lineation Map of Carlton Rhyolite in Blue Creek Canyon

(FROM AIR PHOTOS)

W.C. Hester, 1985

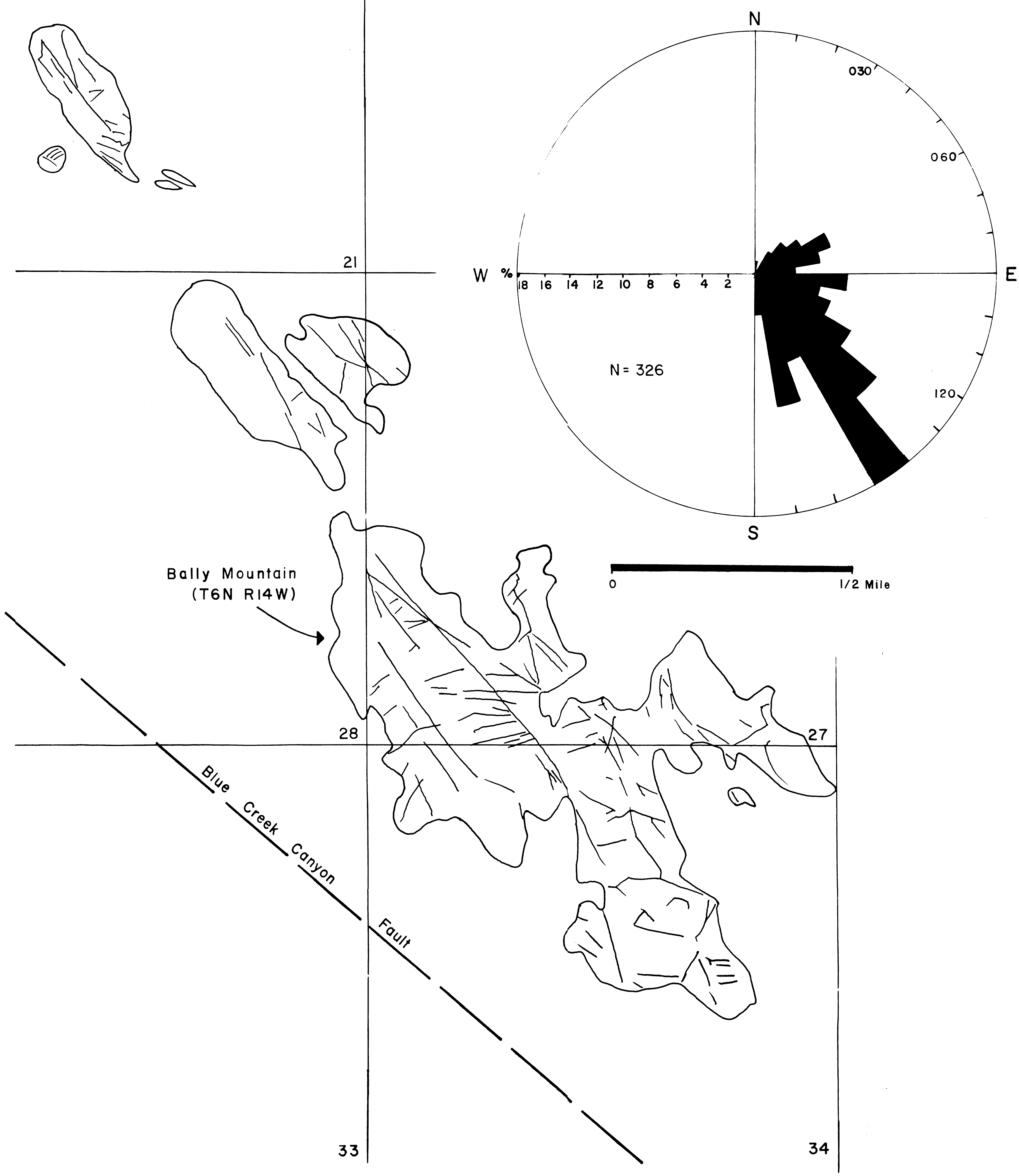


Lineations In Carlton Rhyolite

At Bally Mountain

(*From Air Photos*)

W.C. Hester, 1985



Detail Map of Rhyolite Sheeting on Zodletone Mountain

W.C. Hester, 1985