GEOMETRY OF SURFACE FRACTURES ALONG THE MERVINE ANTICLINE, EASTERN KAY COUNTY: IMPLICATIONS FOR THE ORIGIN OF FRACTURES IN NORTH CENTRAL OKLAHOMA

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CHAPTER I

INTRODUCTION

Statement of Purpose

Exposed at the surface in north-central Oklahoma are relatively flat-lying carbonate rocks of Pennsylvanian and Permian age. However, there are some faults in the subsurface with varying amounts of displacement and broad folds on the surface which can be detected from the slight changes in dips. These structures are usually regarded as related to the Mississippian and Pennsylvanian movement along the Nemaha Ridge (Chaplin, 1988), a major structural feature of the mid-continent region, extending from Minnesota into central Oklahoma. The Mervine Anticline in eastern Kay County, north-central Oklahoma is one of these folds. As is common in most rock outcrops, the rock units outcropping along the Mervine Anticline are highly fractured. Most of these fractures form distinct orthogonal patterns while other fractures form no clear pattern that is readily apparent.

The geometry, mechanics and mechanism of these surface fractures are not well understood. This investigation is primarily aimed at studying and comparing the geometry of fractures from three locations along the axial surface trace of the Mervine Anticline.

The purpose of this study is two-fold: (1) to investigate the effect of structural positioning relative to the fold axial trace on fracture geometry; and (2) to attempt to determine whether the fractures formed strictly through tensional forces or if a shear component was active during their formation. This study should also contribute to our understanding of fracturing in general and, specifically, to a better understanding of rock fracturing in eastern Kay County, Oklahoma.

Location of Study Area

The study area is in eastern Kay County, north-central Oklahoma, approximately 15 miles northeast of Ponca City, Oklahoma. This area is characterized by gently rolling hills and dense vegetation which almost covers any rock outcrops, except where the topography has been cut by the Arkansas River which produces prominent east facing-cliffs. The dominant structure in the area is the Mervine Anticline which produces the largest relief found in Kay County. Where the Arkansas River cuts the anticline, relief is about 300 feet from the crest down to the floor of the river's flood plain. The axial surface trace of the Mervine Anticline has an S-shape that snakes through several sections in T27N, R3E and T28N, R3E. Along the fold, three quarries, Vap's Pass, Dozer Quarry, and Uncas Quarry provide exposures to study the surface fractures in detail. Vap's Pass is located on the north end of the fold at the northern boundary of Sec. 25, T28N, R3E. The Dozer Quarry is located 0.6 miles to the west of the axial trace in the SW 1/4 of Sec.

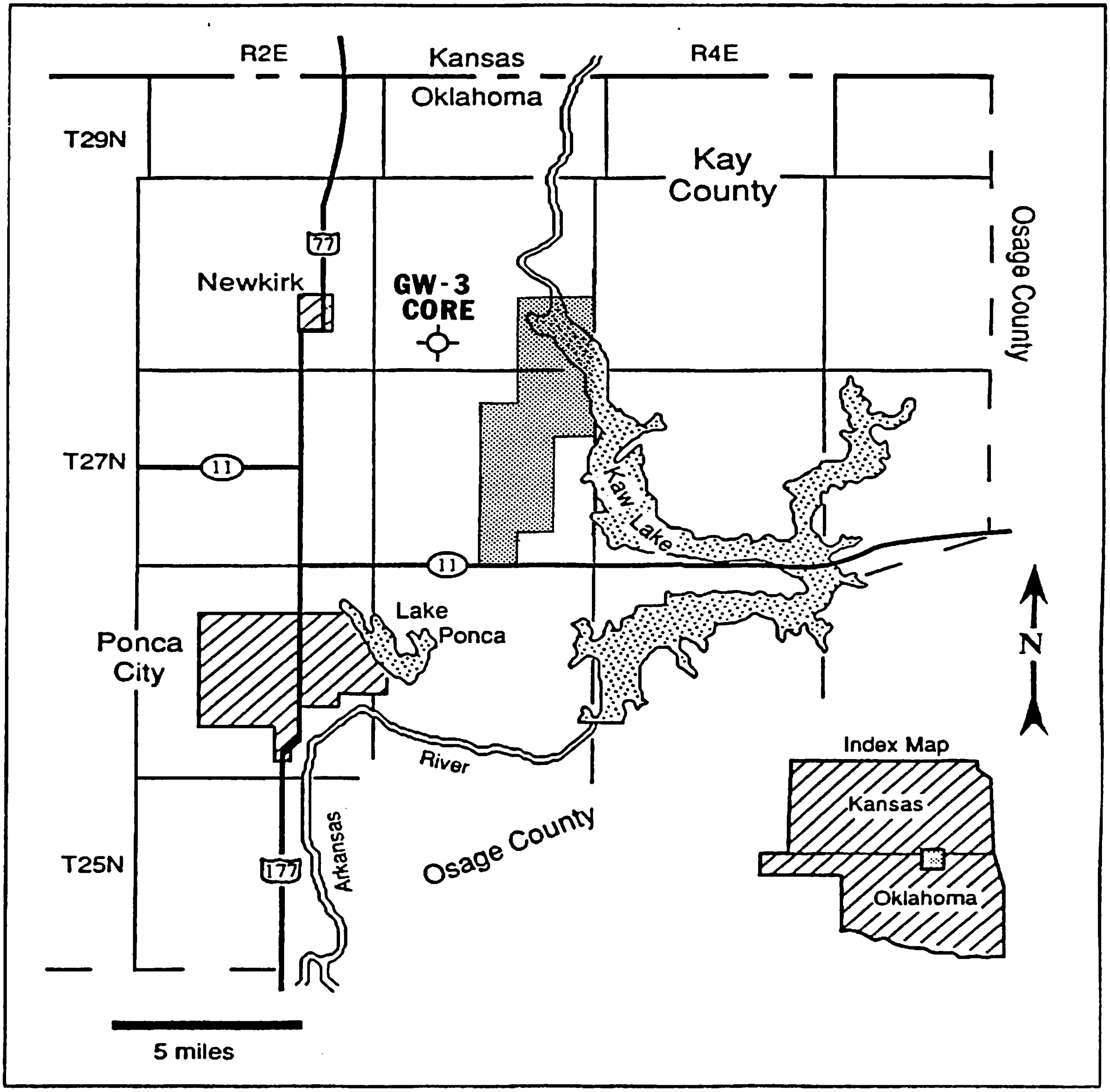

Figure 1. Location of the study area in eastern Kay County, north central Oklahoma (modified from Toomey, 1992).

35, T28N, R3E. The Uncas Quarry is located just off the axial trace to the west in the NE 1/4 of Sec. 27, T27N, R3E (Plate 1). Also studied were thin sections from core GW-3 of the Barneston Formation taken from the Conoco Borehole Test Facility that is approximately 3 miles west of the axial trace in Sec. 33, T28N, R3E (Figure 1).

The study area is accessible through state highways and county roads. Many of the county roads are dirt and sand roads which make accessibility difficult in times of heavy rains. To reach Vaps' Pass, exit Highway 177 at Newkirk, Oklahoma at the stoplight in the center of town and travel east 6.5 miles. To get to the Dozer Quarry from Vaps' Pass, travel 3.5 miles west on the section line road then turn south. After 2 miles turn east and travel 1.5 miles to the entrance of the quarry. To get to the Uncas Quarry from the Dozer Quarry, travel back the 1.5 miles west and then turn south. Travel south 3 miles then turn back east. After 1 mile, turn south and 1.2 miles on the west side of the road is the entrance to the quarry. This quarry must be entered on foot because of fences which block the road.

Method of Study

Critical to the stated objectives of the study was eliminating the effect of varying lithology by selecting sites along an anticline that are located within the same lithologic unit, in this case the Barneston Formation. The impact of bed thickness is considered minimal due to very thin clay layers between the individual limestone beds. The intervening clay layers are not sufficiently thick to prevent the formation from acting as a single mechanical layer. Therefore, within the study area, the Barneston Formation is considered as one mechanical layer.

In order to reach the stated objectives of this study, several tasks were accomplished. These tasks include:

1. Mapping of the fracture geometry in Vap's Pass and Uncas Quarry at a scale of 1 inch equals 8 feet.
2. Compiling a mosaic of photographs of the south wall of the Dozer Quarry in order to view the fracture pattern in cross-section.
3. Collection of fracture orientation data from all three quarries.
4. Plotting collected data on Rose Diagrams and interpreting the fracture geometry.
5. Examination of thin sections from the Barneston Formation in the three outcrops in order to determine if any major lithologic or diagenetic differences exists between the outcrops studied for fracture analysis.
6. Petrographic examination of thin sections for evidence of shearing or preferred orientation of constituents.
7. Comparison of thin sections from surface outcrop to thin section taken from the GW-3 core.
8. X-ray diffraction analysis of fracture filling material from Dozer Quarry to determine origin of material.

Data Collection

Two of the quarries, Vap's Pass and Uncas Quarry have a sufficient amount of bedding surface to allow mapping of the fracture geometry. An area of approximately 2500 feet square was mapped in each quarry on a scale of 1 inch equal to 8 feet. Dozer Quarry, a relatively recent quarry, does not have a large area of available bedding surface and therefore could not be mapped. Instead a mosaic of photographs were made showing the south wall in cross-section.

The criterion for a fracture to be included in the map was for the fracture to have a visible trace length of at least two feet. Also the fractures were divided into two categories, "primary" and "secondary" fractures. The orthogonal fractures were considered to be primary since they are apparently systematic, laterally extensive, have an obvious opening, and show a limited variation in orientation within each quarry. A wide growth of vegetation is usually seen within the fracture openings.. The secondary fractures are restricted within an area surrounded by the primary (systematic) fractures, usually within an orthogon. They have generally little or no opening, very short lengths, highly variable orientation, and terminate against the primary fractures.

In addition to large scale mapping, fracture orientation data were collected using a traverse method which utilizes two mutually perpendicular traverses. Each traverse was 100 feet in length and was approximately parallel to one of the fracture sets. By laying out the traverse in this manner, errors due to the angle difference between the traverse and fracture trend were avoided. Because of their excellent bedding surfaces, Vap's Pass and Uncas Quarry were sampled using this method. In Dozer Quarry, this method was not applicable for data collection due to the lack of bedding surface.

Instead, measurements were taken on the fractures in the quarry walls. A concerted effort was also made in all three quarries to omit fractures which could be a result of man-made events.

The data that were collected from each quarry were plotted on Rose diagrams. In Vap's Pass and the Uncas Quarry, separate Rose diagrams were made for the primary and secondary fractures. In Dozer Quarry, due to the method of data collection, secondary fractures could not be measured, therefore only one Rose diagram showing the primary fractures was plotted was plotted.

Previous Investigations

Geologic investigation in eastern Kay County began in at the turn of the century with early oil exploration. According to Clark and Cooper (1927), who conducted the first subsurface study of oil fields in Kay County and the surrounding area, Gould first discovered the anticline in 1901 and it was first mapped in 1912 by Ohern and Garrett of the Oklahoma Geological Survey. Later studies of the subsurface geology were conducted by Smith (1955) and H. G. Davis (1984). H. G. Davis (1984) proposed left-lateral wrench faulting as the dominant movement on the subsurface fault beneath the Mervine Anticline.

Lawson and Luza completed numerous in depth studies of the Nemaha Uplift between 1977 and 1985. Their work has added tremendously to knowledge on the seismicity of the Nemaha Uplift in Oklahoma. Surface studies have been done by Noll (1955) and Hruby (1955), who mapped the surface geology of southeastern and northeastern Kay County respectively. Chinsomboon (1976) mapped the surface geology along the Arkansas River in Kay County and also suggested that the subsurface fault beneath the Mervine Anticline was a listric normal fault with the fold as an associated rollover anticline. Toomey (1992) conducted a detailed study of the paleontology to determine the depositional environment of the Barneston Formation at Vap's Pass. He also used the microfossils to divide the section into several microfacies and correlated these microfacies with the GW-3 core.

The fracture pattern at Vap's Pass and the surrounding area has been studied by Gasteiger (1980) and Queen and Rizer (1990). Gasteiger (1980) used a calcite strain gage technique to study strain accumulation since the Arbuckle-Ouachita orogonies and the strain distribution about the Mervine Anticline. She concluded that although the accumulated strain was small, the maximum compressive strain lies roughly in the bedding plane and trends west-northwest. Queen and Rizer (1990) compared shear wave anisotropy to core and borehole televiewer data to characterize the subsurface fracture system at the Conoco Borehole Test Facility. They determined from stress-induced borehole breakout that the maximum horizontal compression in this area was between 055 and 075 degrees which is consistent with previously published regional stress orientations. They concluded that the dominant direction of subsurface fracturing, as determined from core, televiewer, and shear wave anisotropy data, is east-northeast, subparallel to the maximum horizontal compression.

CHAPTER II

A BRIEF OVERVIEW OF THE FORMATION OF FRACTURES AND THEIR DESCRIPTION

Introduction

Fractures are probably the most common structural features observed on the earth's surface. According to the Glossary of Geology (Bates and Jackson, 1987), a fracture is defined as "a general term for any break in a rock, whether or not it causes displacement, due to mechanical failure by stress. Fracture includes cracks, joints, and faults". All types of rocks and all geologic settings exhibit fracturing to some degree. Fractures are the dominating element in the formation of many natural scenic attractions such as the Devils Tower in Wyoming, the arches of Arches National Park in Utah, and Monument Valley in Utah and Arizona. Fractures also have a profound effect on the movement of ground water, hydrocarbons, and contaminants. The importance of fractures in the recovery of hydrocarbons can be seen in a technique used by the oil industry to artificially fracture the rock by hydrofracturing methods to increase the fracture permeability and thereby increasing the yield (G. H. Davis, 1984).

When a fracture forms, it begins at a point in the intact rock and propagates outward from that point of initiation. The line that separates the intact rock from the fractured rock is the propagation front. The propagation front moves through the rock as the fracture grows.

Different fracture types are distinguished by the stress regime in which they form (Figure 2). Joints are fractures that are associated with opening displacements. These fractures are termed mode I fractures and have movement perpendicular to the fracture surface. Faults are associated with shearing displacements that have movement parallel to the fracture face and either perpendicular to the propagation front (mode II) or parallel to the propagation front (mode III) (Pollard and Aydin, 1988).

Fracture Morphology

The features that can be seen on the face of the fracture will give important information about the mode in which the fracture formed. The classification of a fracture as a joint depends to a large part on the presence of these distinctive fractographic markings that are very delicate in nature and subject to easy erosion. Woodworth (1896) gave a very detailed description of these structural features, and his drawings are still being used today. These features include origins, hackles, and rib marks, which are collectively called plumose structures (Figure 3). The origin of an extension fracture is commonly an inclusion or other such flaw in the rock which causes a local increase in stress which effectively reduces the overall strength

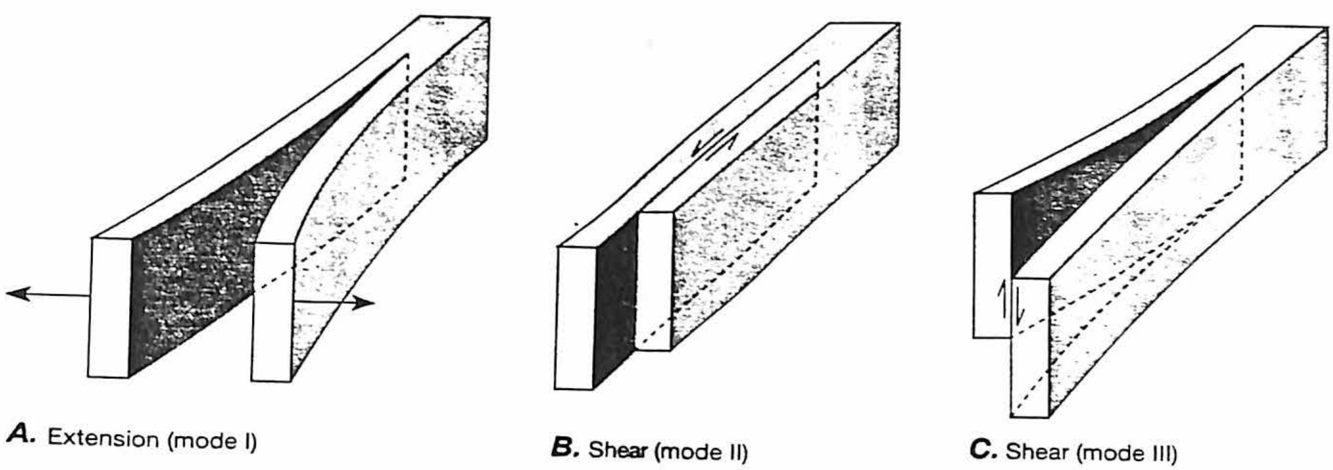

Figure 2. Drawing illustrating the three modes of fracture formation (from Twiss and Moores, 1992).

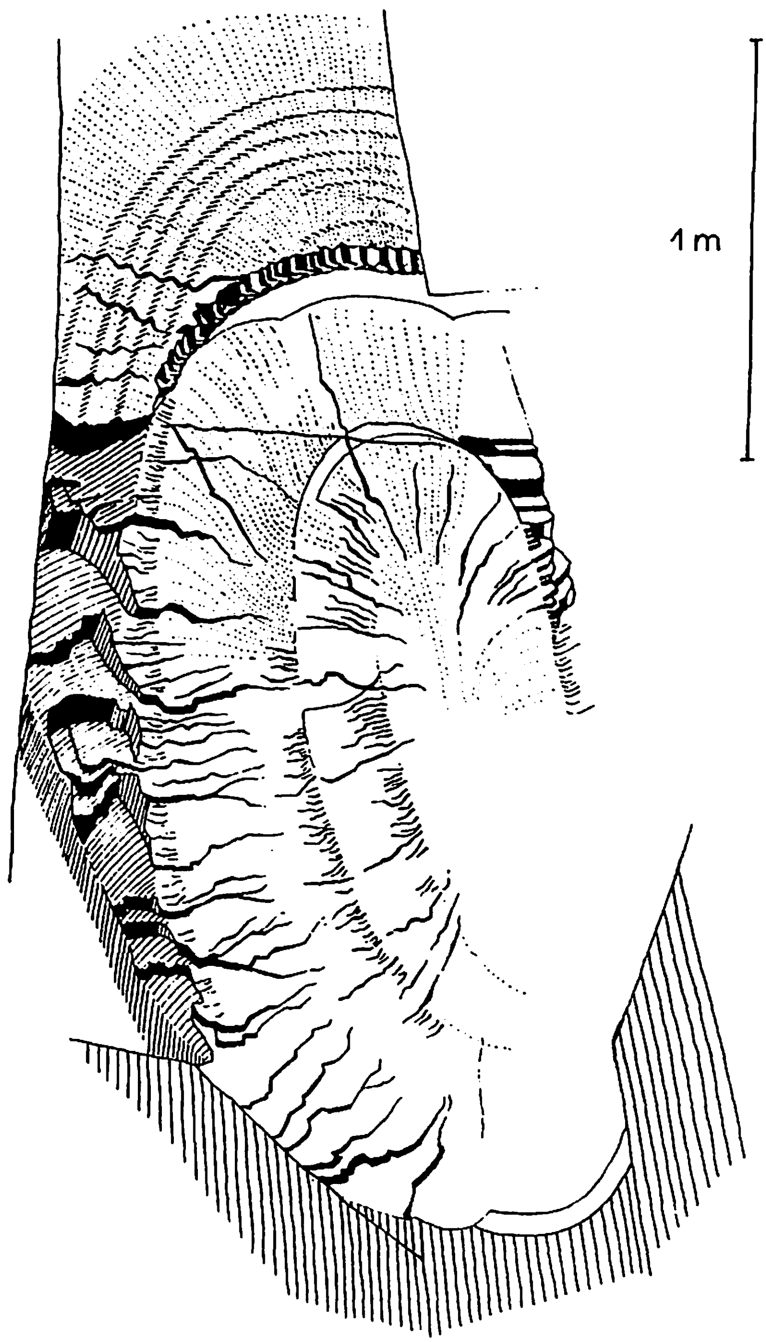

Figure 3. Line drawing showing the distinctive markings that occur on a fracture surface (from Dennis, 1972).

(Narr and Suppe, 1991). Hackle marks are curvilinear boundaries that are centered on the origin or fan away from a curvilinear axis and indicate the local propagation direction. The rib marks are curvilinear and are oriented perpendicular to hackles and plume axes (Woodworth, 1896). These rib marks have been interpreted by many researchers as arrest lines where the propagation of the fracture temporarily halted (Twiss and Moores, 1992). Since these markings indicate movement perpendicular to the fracture surface, without them it is impossible to call a fracture a "joint" with any degree of certainty. Without these markers they should instead simply be called fractures. The term fracture will be used here in the general sense without any distinction between a joint and a fracture unless so stated.

The plumose structures are very delicate and easily weathered. They are also most easily seen in fine-grained rocks such as silt stone and limestone. Often the lighting must be at just the right angle for the plumose structures to be seen, so they are often missed simply due to bad timing (Pollard and Aydin, 1988). When a plumose structure is seen, it is an excellent indicator for distinguishing a mode I fracture from a mode II or mode III fracture. However, some workers argue that plumose structures are not indicative of mode I fracturing, but are instead associated with shear fractures (Pollard and Aydin, 1988).

Slickenside lineations also often appear on fracture faces and indicate shearing. Slickensides are linear features that form on the face of a fault, parallel to the direction of slip (Twiss and Moores, 1992). Their presence does not necessarily indicate that the fracture formed by mode II or mode III opening. The slickensides may be formed as a result of shearing during fracture initiation as in modes II and III, or formed by later shearing along a fracture that originally formed by mode I opening.

Fracture Spacing

One of the most obvious qualities of fractures is the apparent relatively constant spacing between the fractures of any given set (Narr and Suppe, 1991). This spacing is dependent on several variables: lithology, porosity, grain size, burial history, structural position, and bed thickness. Of these, bed thickness is the most visible factor and is well studied. Harris et al.(1968) pointed out that several thin bedded units may behave as a single mechanical layer. Narr and Suppe (1991) used the term mechanical layer instead of beds because a fracture is confined to a mechanical layer and not necessarily to a single bed. Therefore, while many workers use bed thickness as a critical variable, the mechanical layer thickness is actually a more accurate description of this variable.

D. W. Hobbs (1967) proposed a mathematical explanation for the formation of tension joints in sedimentary rocks. He concluded that joint spacing is proportional to:

(a) bed thickness

(b) the square root of the bed's Young's Modulus

(c) the inverse of the square root of the shear modulus of the neighboring beds.

His theory also predicts that joint frequency will increase with increasing tectonic deformation.

Two assumptions that must be met for Hobbs' model are that the thickness of the jointed layer is less than or equal to the thickness of the lower-modulus neighboring bed and that no slip occurs at the interface (Narr and Suppe, 1991).

Hobbs' model is based on the fact that the stress that is released by a single joint only releases the stress for a short distance normal to the fracture while the rest of the layer remains close to the fracture stress. According to Hobbs' model (1967) the first joint will form in the rock at the weakest point. As the tensile strain increases, then one of the tensile stresses will reach the tensile strength of the rock and the rock will rupture. This will release the tensile stress in the vicinity of this first joint, leaving the tensile stress in the remainder of the bed near the tensile strength of the rock. Additional joints will form at finite distances from the first joint (Hobbs, 1967). This mechanism proposed by Hobbs' model as well as mechanisms proposed by others, all predict that as bed thickness increases, fracture spacing will also increase. However, this linear relationship loses its validity where the thickness is greater than 1.5 meters. Ladeira and Price (1981) stated that in beds thicker than 1.5 meters, hydraulic fracturing mechanics were dominant while in beds less than 1.5 meter thick, mechanisms which rely on transmission of stress through the adjacent lower modulus beds dominate. The result is that as bed thickness increases past 1.5 meters, the rate of increase in the distance separating fractures will slow until a maximum fracture spacing is reached.

Narr and Suppe (1991) conducted experiments testing Hobbs' model. A simple diagram illustrating Hobbs' model is shown in Figure 4 where a jointed layer lies between two lower modulus layers. Along the y-axis, the tensile stress increases and the tensile strength of the rock is shown at C_0. The x-axis is the distance along the bed and the initial joints, which have a tensile stress of zero across them, are noted by F_0. Figure 4a shows the tensile stress increasing due to a far-field extensional strain. The tensile stress increases until reaching the tensile strength of the rock, at which time a joint will form and tensile stress across the newly formed joint will go to zero. This new joint, F_1, will form midway between the existing fractures where the tensile stress is maximum. Figure 4b shows this stress distribution. With continued extension, new fractures, F_2, will form at the midpoints between the existing fractures (Figure 4c).

Narr and Suppe (1991) compared the spacing distribution of joints based on Hobbs' model with observed data collected in the Monterey Formation of California. They found that the observed distribution did not match the simulated distribution as predicted by Hobbs' model. Plotted on a linear histogram, the observed data contained a single peak while the simulated distribution was multi-peaked. They determined that this difference was due to flaws contained in the rock that Hobbs' model does not account for.

The presence of a flaw in a bed will effectively reduce the strength of the rock by magnifying the stress in the immediate vicinity of the flaw. These flaws include both microscopic and macroscopic features.

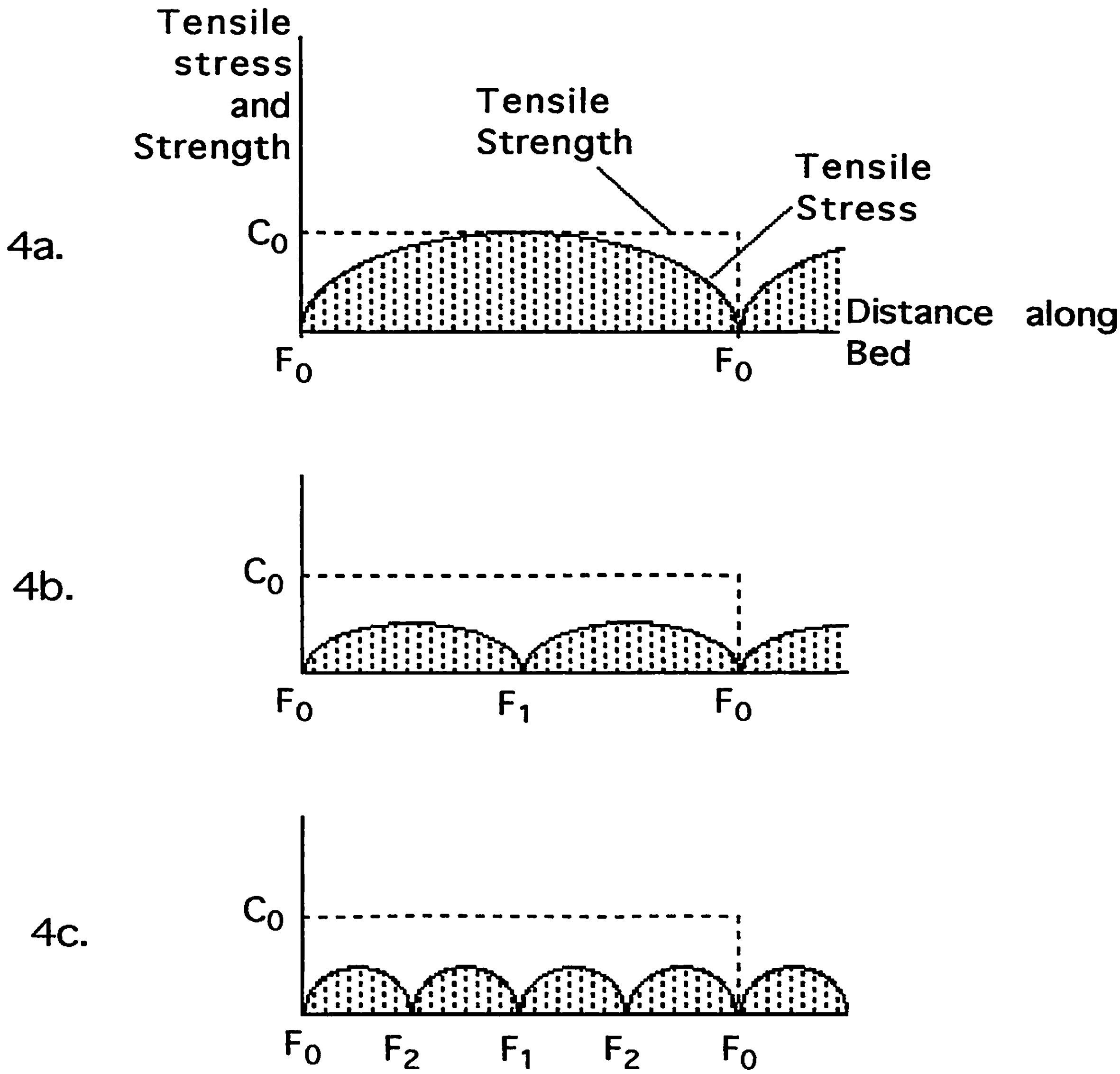

Figure 4. Diagram showing Hobbs' Model of fracture initiation (after from Narr and Suppe, 1991).

A. A. Griffith (1921,1924) proposed a myriad of microscopic and sub-microscopic cracks, randomly oriented with respect to each other, that reduce the strength of the rock. These cracks are now commonly referred to as Griffith Cracks. They are envisioned as small, elongate features with the major axis being much longer than the minor axis. When a stress is applied to one of these cracks, the crack tip experiences a local concentration of tensile stress. If the applied stress is a uniaxial tensile stress perpendicular to the major axis, the local tensile stress at the crack tip can theoretically be as high as 2 orders of magnitude greater than the uniaxial applied stress (Twiss and Moores, 1992). Even if the stress is a uniaxial compressive stress, the Griffith cracks whose major axis is parallel with the applied stress will experience local tensile stress at the tip, oriented normal to the applied compressive stress (Twiss and Moores, 1992). According to Narr and Suppe (1991), these microcracks will magnify stress, and reduce the overall tensile strength of the rock but are so pervasive in rock that they do not have any impact on the joint spacing distribution. Of more importance are macroscopic flaws, such as fossils, concretions, bedding plane irregularities or other inhomogeneities which are often the origin of joints (Pollard and Aydin, 1988). Because the stress magnification increases by the square of the flaw or crack length, macroscopic flaws will have a much greater impact on joint spacing than the Griffith Cracks will have (Narr and Suppe, 1991).

Figure 5 shows the original Hobbs' model except that Narr and Suppe (1991) have modified it by the addition of flaws at random locations along the centerline of the bed. The flaws, labeled f_1, f_2 . . .

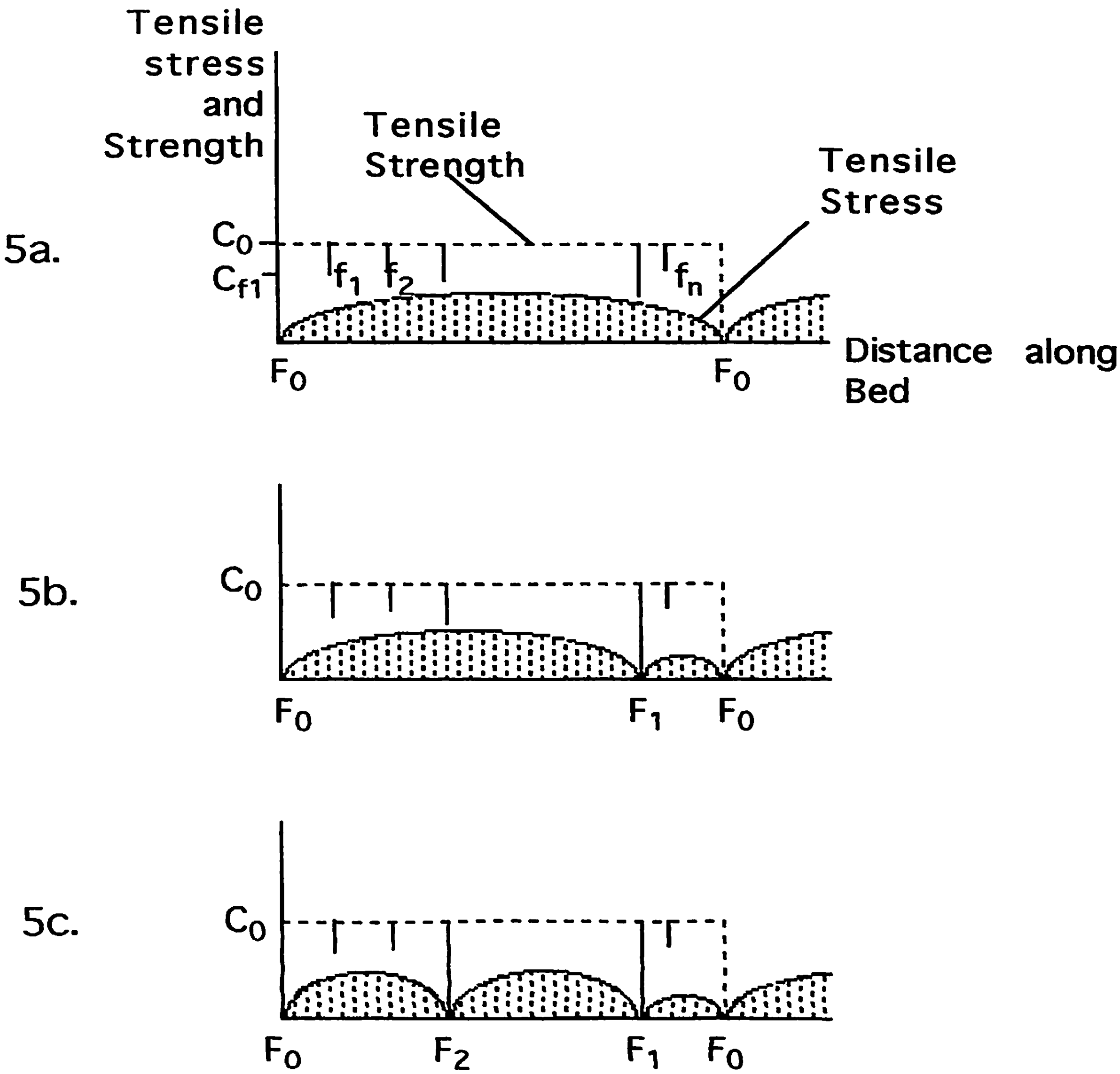

Figure 5. Diagram showing Hobbs' model with the addition of flaws at random locations (after Narr and Suppe, 1991).

f_n, reduce the tensile strength of the rock by varying amounts and are shown in figure 5a. The length of the line represents the relative effect on tensile strength, i.e. the longer the line, the greater the reduction in tensile strength. Therefore the strength of the bed at flaw f_1 is C_{f1} and the strength away from the flaw remains C_0. When this is subjected to a far-field extensional force, the tensile stress still increases according to Hobbs' model, assuming that the flaws do not perturb the stress field to the extent that the fractures do. As the tensile stress increases, a joint will form wherever the tensile stress equals the tensile strength of the rock. Although the tensile stress will reach its' maximum value midway between the existing fractures, the new joint will commonly at a flaw (figure 5b). Further fracture development will proceed as shown in figure 5c.

Narr and Suppe (1991) found that the distribution of joints achieved by the addition of flaws more closely resembled the observed distribution of fractures in the Monterey Formation than did the original Hobbs model. They also found that as the number of flaws approached and then exceeded the number of joints in their simulations, the distribution of joints resembled that predicted by Hobbs' model. The simulated distribution that most nearly resembled the observed distribution occurred when the final joint count was 4-5 times the number of initial flaws.

Fracture Sets

At any locality, a single fracture, only, is rarely observed. More commonly, they are observed as groups of parallel fractures called fracture sets. When two or more fracture sets intersect at fairly constant angles, they constitute a fracture system (Dennis, 1972). Fractures also occur in sets that are called systematic where they are roughly planar, parallel, and evenly spaced (G. H. Davis, 1984). Other fractures that have irregular spacing, shape, or orientation and cannot be grouped into distinctive through-going sets are called nonsystematic fractures (G. H. Davis, 1984). Most outcrops contain both systematic and nonsystematic fractures and the intersection between the different joint sets can give information about the timing of joint formation.

If two joint sets are nonparallel and formed at the same time, then the two sets will cross-cut each other with little or no apparent joint interaction (Goldstein and Marshak, 1988). However, if the two sets form at different times, the first to form will be a free surface which will prevent the transmission of stresses across it (Goldstein and Marshak, 1988). The second fracture to form will then terminate against the first fracture. Another result of the free surface effect of the first fracture is to locally modify the stress field such that the maximum principal stresses are parallel or perpendicular to the fracture surface. This modification of the stress field causes the second fracture to curve either towards the first fracture or away from it. These features are most common in mode I fractures because they form parallel to the maximum principle stress. If the stress field is modified so that the maximum principle stress (σ_1) is perpendicular to the pre-existing fracture, the later forming mode I fracture will form parallel to the new σ_1 direction. This new condition will cause it to bend towards the older fracture.

Goldstein and Marshak (1988) name the bending of one fracture towards another as hooking. The younger fracture is always the fracture which bends or terminates against the older fracture (Goldstein and Marshak, 1988). This hooking is also seen where the termination of two fractures overlap. Figure 6 shows three types of fracture interaction. Figure 6a illustrates two fractures that formed simultaneously, that terminate by hooking towards each other. Figure 6b shows a younger fracture terminating against an older fracture by bending towards the older fracture and intersecting it at a right angle. The third type of intersection occurs when the younger fracture intersects the older fracture by bending away from it and becoming parallel to it (figure 6c).

While fractures occur as continuous features across large areas as a result of regional stress, they also form as a result of local features, such as folds. The geometry of these fractures is closely related to the orientation of the fold and three classes of fractures have been identified: cross fractures, longitudinal fractures, and oblique fractures (Figure 7). Cross fractures are aligned perpendicular and longitudinal fractures are parallel to the fold axis. Both have been interpreted as mode I fractures. Oblique fractures are at angles to the fold axis and commonly form conjugate sets of shear fractures (G. H. Davis, 1984).

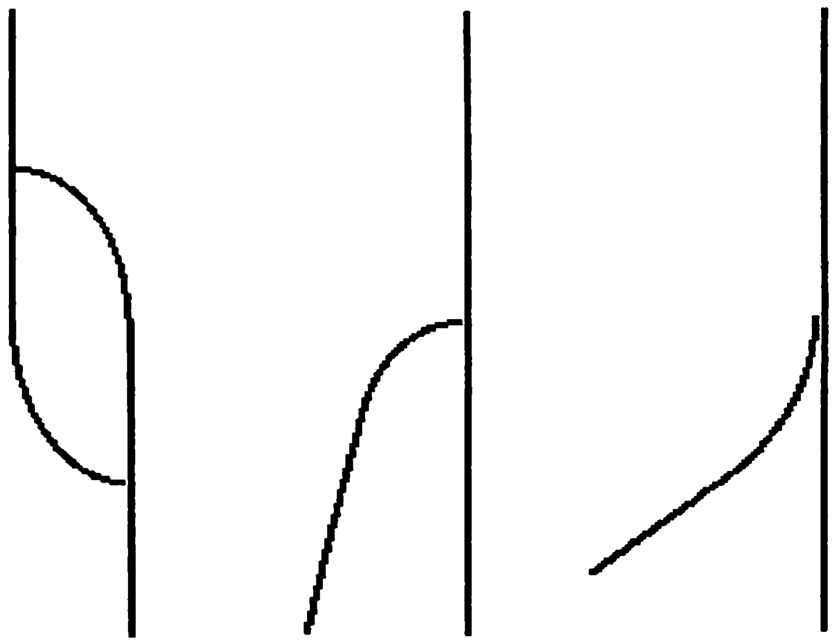

Figure 6. Three common geometries of fracture interaction at fracture termination (from Twiss and Moores, 1991).

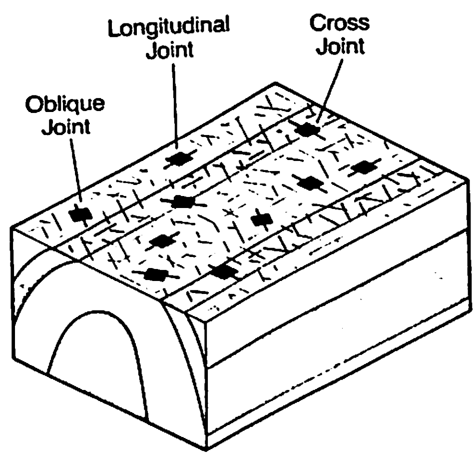

Figure 7. Idealized diagram showing the relation of joints to folds (from Davis, 1984).

CHAPTER III

GEOLOGY, STRUCTURE, AND GEOLOGIC HISTORY OF EASTERN KAY COUNTY

Stratigraphy

The rock units studied in this work are members of the Barneston Formation. Plate 1 is a geologic map of the study area that was compiled from work conducted by Hruby (1955), Noll (1955), and Chinsomboon (1976). These rocks are of Early Permian (Wolfcampian) age, and are assigned to the Chase Group (Figure 8). This group is approximately 300 feet thick and includes all beds between the base of the Wreford Limestone and the top of the Herington Limestone. The limestones are generally 25-30 feet thick and contain a wide assemblage of fossils including foramnifers, trilobite fragments, mollusc fragments, and echinoid spines (Toomey, 1992). Also present is abundant chert, most notably in the form of nodules. The interbedded shales are generally 30-40 feet thick and the sandstones where present, are lenticular. Regionally these units strike roughly north-south and dip gently, one to three degrees to the west but the dip may locally exceed ten degrees (Chaplin, 1988). The Barneston Formation consists of three members; the lowermost

SYSTEM	SERIES	GROUP	FORMATION
PERMIAN	WOLFCAMPIAN	CHASE	HERINGTON LIMESTONE
			ENTERPRISE SHALE
			WINFIELD LIMESTONE
			DOYLE SHALE
			BARNESTON LIMESTONE
			MATFIELD SHALE
			WREFORD LIMESTONE

Figure 8. Generalized stratigraphic section of the Chase Group in north central Oklahoma (after Chaplin, 1988).

member is the Florence Limestone, overlain by the Oketo Shale and the Fort Riley Limestone, respectively. The Oketo Shale, which separates the two limestone members in northern Kansas, thins and is absent altogether further south. In the study area, this shale is absent and the Fort Riley Limestone conformably overlies the Florence Limestone (Chaplin, 1988). The Florence Limestone was originally named for exposures near Florence, Kansas in 1902 by C. S. Prosser (in Toomey, 1992). This limestone is a thin to medium bedded skeletal wackestone which, in the study area, is approximately seventeen feet thick. Included near the top of this unit is a layer of cannonball chert nodules which are elliptical in shape with the long axis being parallel to the bedding plane. This chert layer also has long been the basis for determining the top of the Florence Limestone (Noll, 1955). Toomey (1992) used microfacies analyses to place the top of the unit ten feet above the chert layer. This was done because the chert layer does not have a consistent occurrence throughout the Florence Limestone outcrop area. While this boundary placement may be a more accurate delineation of the top of the unit, it is not easily recognizable in the field. The chert layer is used here as the top of the Florence Limestone since it is present throughout the study area.

The Fort Riley Limestone is composed of massive algal limestones in the lower portion which are overlain by a sequence of alternating beds of fossiliferous shaly limestones and calcareous shales. It is approximately 40 feet thick where the section is complete. In the quarries selected for this study, the top of the Fort Riley has been removed by erosion (Toomey, 1992).

The microfacies analysis conducted by Toomey (1992) compared the section of Barneston present at Vap's Pass to the Barneston in the subsurface. The subsurface section was obtained from the GW-3 well at the Conoco Borehole Test Facility. Toomey (1992) conducted his correlation through study of over 100 thin sections from outcrop and core samples. Through analysis of the fossil assemblages, particularly the fusilinids *Oketalla*, *Nankinella*, and *Schwagerina*, several microfacies were determined as well as depositional environments for each microfacies. The microfacies divisions in the core and outcrop are similar except that the core contains seven microfacies while the outcrop has only six because the seventh microfacies at Vap's Pass has been removed by erosion. The individual microfacies in both the core and the outcrop are similar in content although some microfacies are slightly thicker in the core (Figure 9). He noted that one Florence microfacies at Vap's Pass contains two thin shale beds while the corresponding core microfacies only shows a slight increase in shaliness.

Toomey (1992) concluded that the Barneston Formation was deposited in a marine environment with water depths between five and fifty feet. The repetitive nature of the units indicated a continual shifting from an agitated shallow marine environment to a deeper, calmer environment. He noted the presence of two complete shallowing upward sequences present where the base of the Florence was deposited in shallowing, slightly agitated water. He found no evidence to suggest that the Barneston Formation experienced any sub-aerial exposure during deposition.

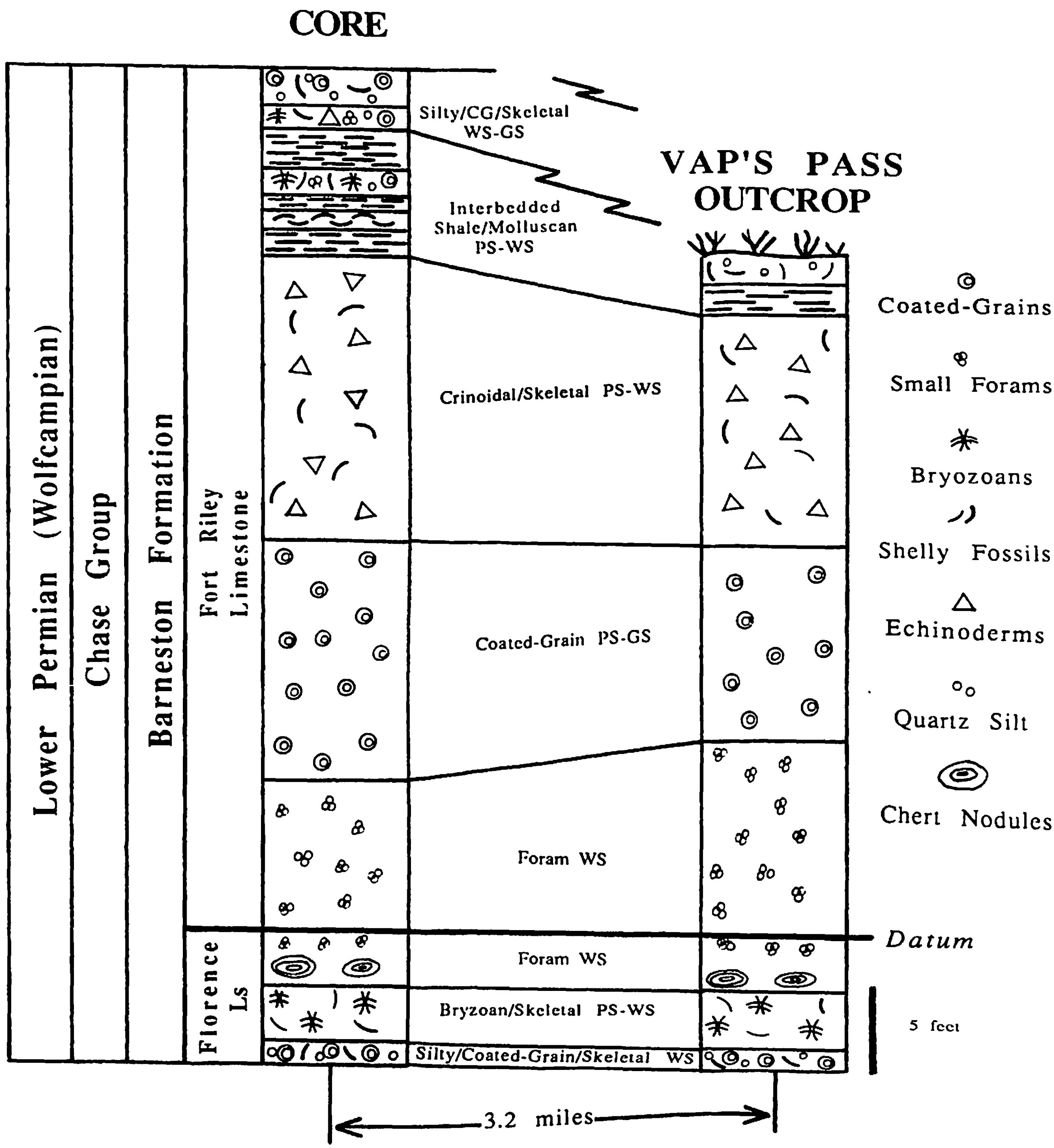

Figure 9. Microfacies correlation between Vaps' Pass and the subsurface core from the Conoco Test Facility (modified from Toomey, 1992).

Structure

The Nemaha Ridge is the major tectonic feature of central Oklahoma and extends 900 miles northward into Minnesota (Toomey, 1992). Northeasterly and northwesterly trending faults characterize the Nemaha Ridge in the subsurface Pennsylvanian units (Luza and Lawson, 1981), but these faults tend to die out upward in the section (Gasteiger, 1980). Therefore they are not detectable on the surface although many of these faults have folds associated with them. Among these folds are the Blackwell, Ponca City, Mervine, and Dexter Anticlines (Gasteiger, 1980). Luza and Lawson (1981) interpreted these structures as drape folds over proposed high-angle, basement-involved normal faults. Gasteiger (1980) reported that workers in Kansas have found evidence for a left-lateral strike-slip component on the faults with the associated folds forming a series of en echelon folds.

In the study area the structure is dominated by the Mervine Anticline. The axial surface trace of this fold trends approximately 020 degrees and curves to almost due south at its southern end (Plate 1). The western flank dips between 3 and 4 degrees west and quickly merges into the regional dip. The eastern Flank dips up to 30 degrees east, which gives the anticline a definite asymmetrical profile (H. G. Davis, 1984). The eastern flank is also bounded by a fault which is one of the northeast-trending faults of the Nemaha Ridge. This fault is not evident at the surface but can be inferred by earthquakes that have been recorded in the subsurface (Luza and

Lawson, 1981). This leads most observers to classify the Mervine Anticline as a drape fold over the fault with the west block uplifted and the east block downthrown.

Chinsomboom (1976) interpreted the Mervine Anticline as a rollover anticline with the fault to the east as a listric normal fault down to the west. According to H. G. Davis (1984) the area surrounding the Mervine anticline has very dense well control and none of these wells cuts a fault, indicating a fault of high angle. If, as Chinsomboon (1976) suggests, the fault is listric normal then the dip angle of the fault should decrease at depth and should cut several wells. That this does not happen makes the interpretation of a listric normal fault improbable.

Another interpretation has the dominant structural style as wrench (strike-slip) faulting. H. G. Davis (1984) sites the geometric pattern of the observed structural features as evidence for a left-lateral strike-slip deformation. Since this fault has not been mapped on the surface, H. G. Davis (1984) inferred the evidence from: (1) the Mervine Anticline's relationship with other folds forming apparent en- echelon folds; (2) the presence of a high angle master fault; and (3) the geometry of the en echelon folds and the master fault.

The Mervine Anticline has also been considered as a continuation of the Ponca Anticline to the southwest and has a parallel trend to the Dexter Anticline to the northeast (Noll, 1955). This continuation of folds supports the interpretation of the Mervine Anticline as a drape fold over a normal fault. In addition, the fracture sets that are present also show no evidence of offset, which also supports the drape fold hypothesis.

Geologic History

Based on the available geological literature in the north central Oklahoma and surrounding areas, the geologic history may be summarized a follows:

Deposition of sediments began when an epeiric sea transgressed over Precambrian igneous rocks in Late Cambrian and Early Ordovician. This transgression led to the deposition of the Arbuckle carbonates (H. G. Davis, 1984). An episode of uplift started In Middle to Late Ordovician which resulted in the uplift of the Ozark Dome which continued through to the end of Devonian time and formed part of the transcontinent arch north and east of Oklahoma (Noll, 1955).

According to H. G. Davis (1984), a regression at the end of Early Ordovician time resulted in an unconformity at the top of the Arbuckle Group. Another transgression from Middle Ordovician through Silurian and into Early Devonian resulted in deposition of the Simpson Group. Regression and erosion during Middle to Late Devonian resulted in the removal of the majority of the Simpson Group. Transgression in Late Devonian to Early Mississippian resulted in the deposition, in a deep water, reducing environment, of the black Woodford Shale on top of the Bromide Sandstone of the Simpson Group. This deposition continued in a shallower environment and deposited Osagian carbonates and Chesterian carbonates and clastics. This deposition was followed by Pennsylvanian deposition of the clastic Morrow and Atoka units which was followed by an erosive event that removed the stratigraphic record until only a remnant of Osagian limestone remained (H. G. Davis, 1984). This event also left a rubble zone on top of the Osagian limestone, which is known as the "Mississippi Chat". This was also the time of major tectonic activity along the Nemaha Ridge (Chaplin, 1988) which is an 1100 Ma paleo-rift zone that originated due to extensional forces (Sloss, 1988). Although most of the movement took place during the Pennsylvanian, which was a time of widespread uplift, the Nemaha Ridge continues to be active today as can be shown by the distribution of earthquakes in central Oklahoma (Lawson and Luza, 1984).

According to H. G. Davis (1984), regression and erosion removed the earlier units until only a remnant of the Osagian Limestone remained. This erosional event resulted in the deposition of a zone of detrital chert known as the Mississippi Chat. This event was followed by a long period, from Pennsylvanian to the end of Early Permian, of almost continual deposition of sediments. These units are interbedded shales, sandstones, and limestones and record many transgressions and regressions.

From Late Permian, through the Triassic and into the Jurassic, there was a long period of nondeposition. In Cretaceous, the sea again transgressed and deposited a large amount of sediment that was later removed by a large Cenozoic erosional event which removed units down to the present levels where Lower Permian units are all that are exposed in the area (H. G. Davis, 1984).

CHAPTER IV

FRACTURE GEOMETRY

Vap's Pass

Figure 10 shows the fractures mapped at Vap's Pass at a scale of 1 inch equals 8 feet. The heavy lines represent the primary fractures and the thin lines represent the secondary fractures. The secondary fractures are restricted to the area of orthogons defined by the primary fractures. They hook to the primary fractures with a bend along their strike. The bending that is seen in the secondary fractures falls into two classes: the first class shows a gradual bending over an extended distance while the second class has a sharp bend followed by a length of fracture that shows no bending. All of the hooking in the secondary fractures is of the type that hook towards the older, pre-existing fracture. The primary fractures do not show any evidence of hooking and are not consistent in orientation over the length of the fracture, but are composed of joined line segments of slightly different orientations (Queen and Rizer, 1990).

The fracture pattern at the Vap's Pass Quarry is dominated by two primary fracture sets (Figure 11A). One set trends between

Figure 10. Map of Fractures at Vaps' Pass. The numbers 7 - 12 represent sample locations.

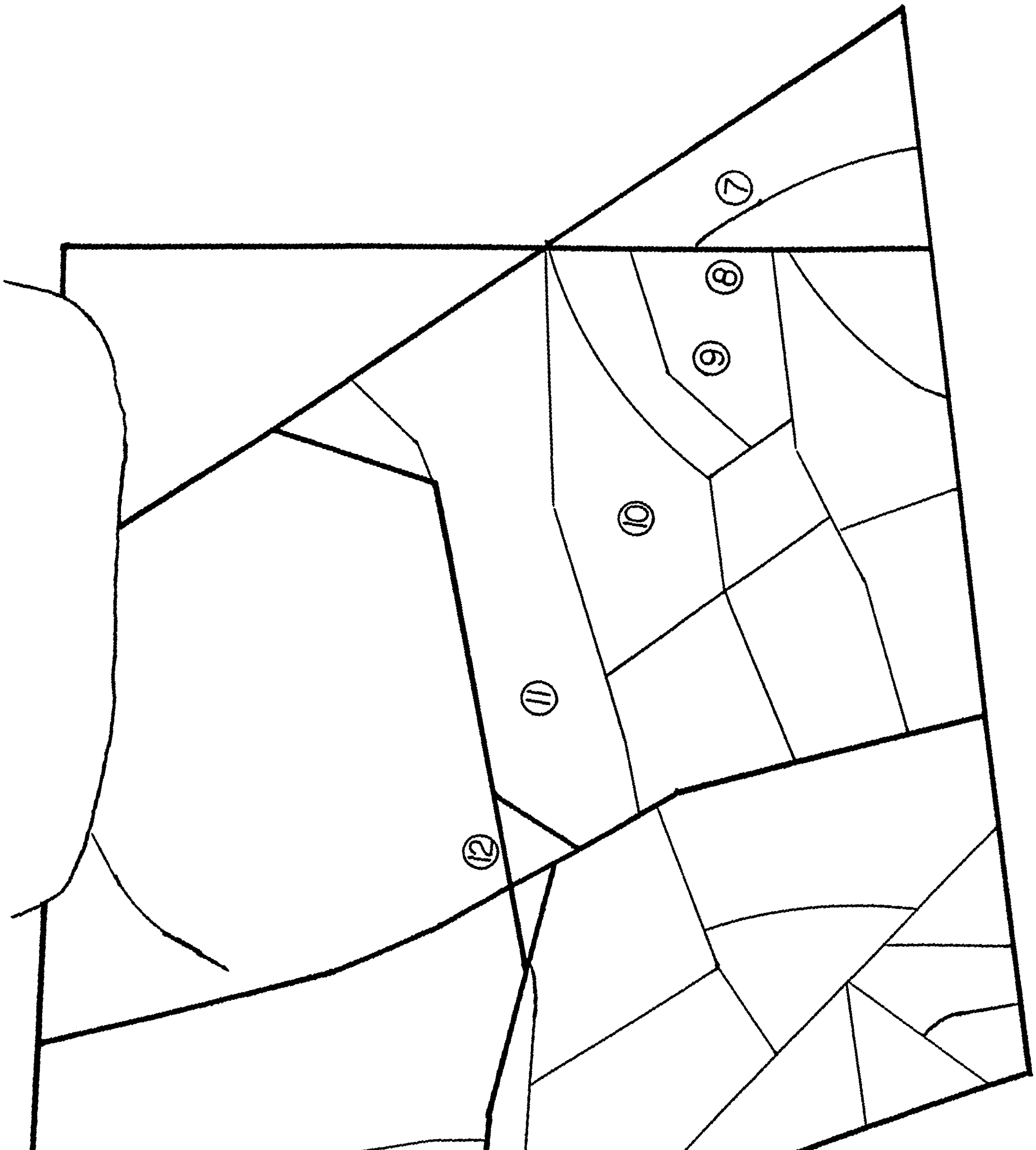

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Figure 11. A. Photograph showing the orthogonal fracture system on the upper bedding surface in Vap's Pass.

B. Photograph showing a fracture zone in the south side of the roadcut at Vap's Pass.

070 and 080 degrees, while the other set trends between 320 and 325 degrees (Figure 12). These two fracture sets make up a very well defined orthogonal fracture system which is easily seen throughout the area. Also present is a less prominent set of fractures trending 345 to 350 degrees.

The overall variation in orientation of secondary fractures can easily be seen, although a slight preference does exist between 060 and 065 degrees, on a Rose diagram (Figure 13). These secondary fractures are possibly due to a very local event such as differential compaction resulting from differing thickness of the interbedded shale layers. The areas that are underlain by a thick layer of shale will experience more flexure of the bed because the shale layer will undergo a greater amount of compaction. Conversely, where the shale layer is thinner, the shale layer will not compact and the bed will be supported by the underlying limestone bed and not flex.

The fractures at Vap's Pass can also be viewed in cross-section along a roadcut which passes through the quarry (Figure 11B). The roadcut runs approximately E-W through the quarry which is almost parallel to the 070 degrees fracture set. In cross-section, the distinction between primary and secondary fractures is more difficult, although some fractures do show a wider gap and tend to cut across all bedding planes, while other, smaller fractures are contained within individual beds. The fractures also are nearly vertical and normal to the bedding planes. Some exceptions do exist, but the angle of dip is still very high, between 80 and 90 degrees.

The vertical faces along the roadcut show areas of highly concentrated fractures that are called here as "fracture zones" (Figure

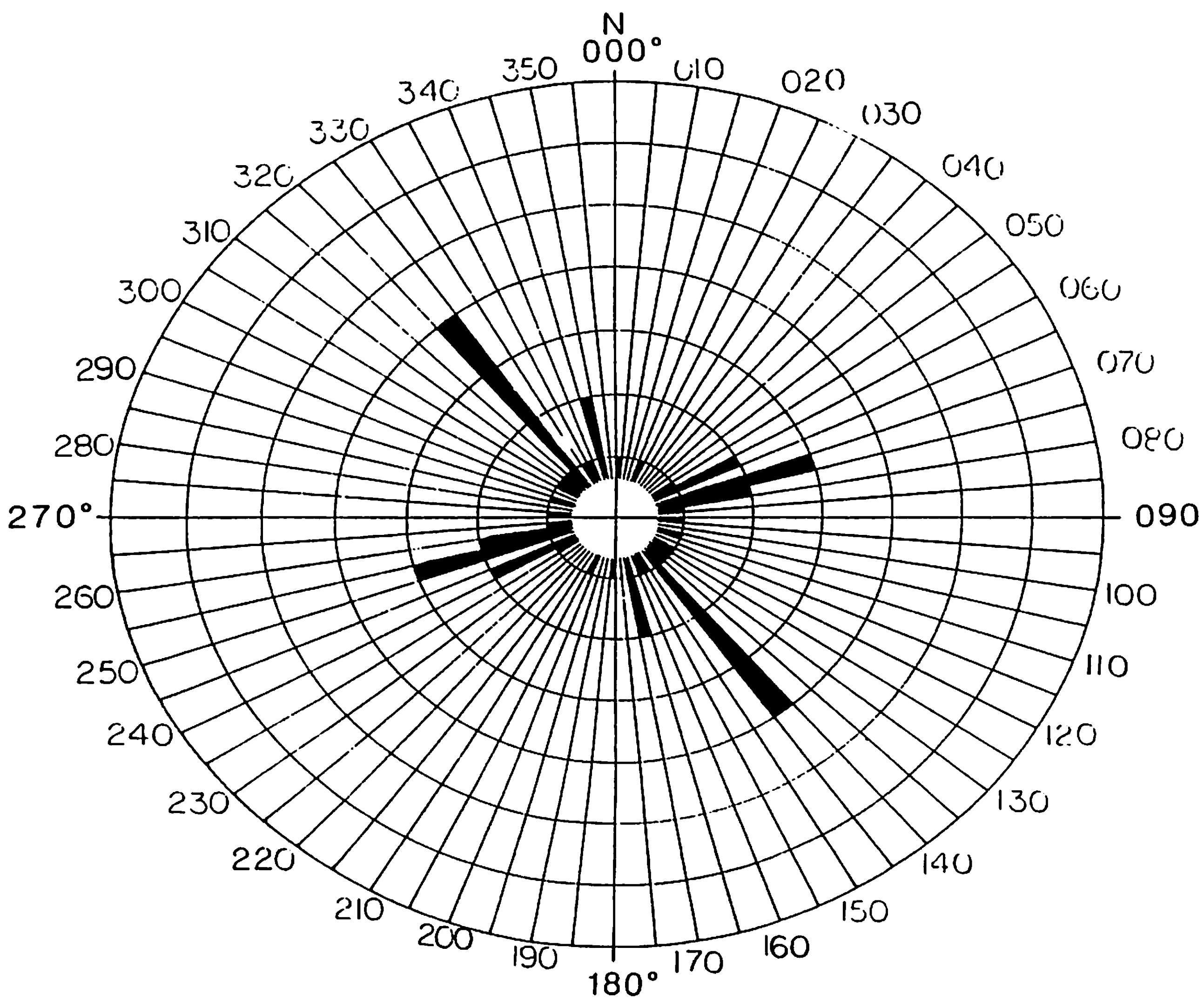


Figure 12. Rose diagram showing the primary fracture pattern in Vap's Pass Quarry.

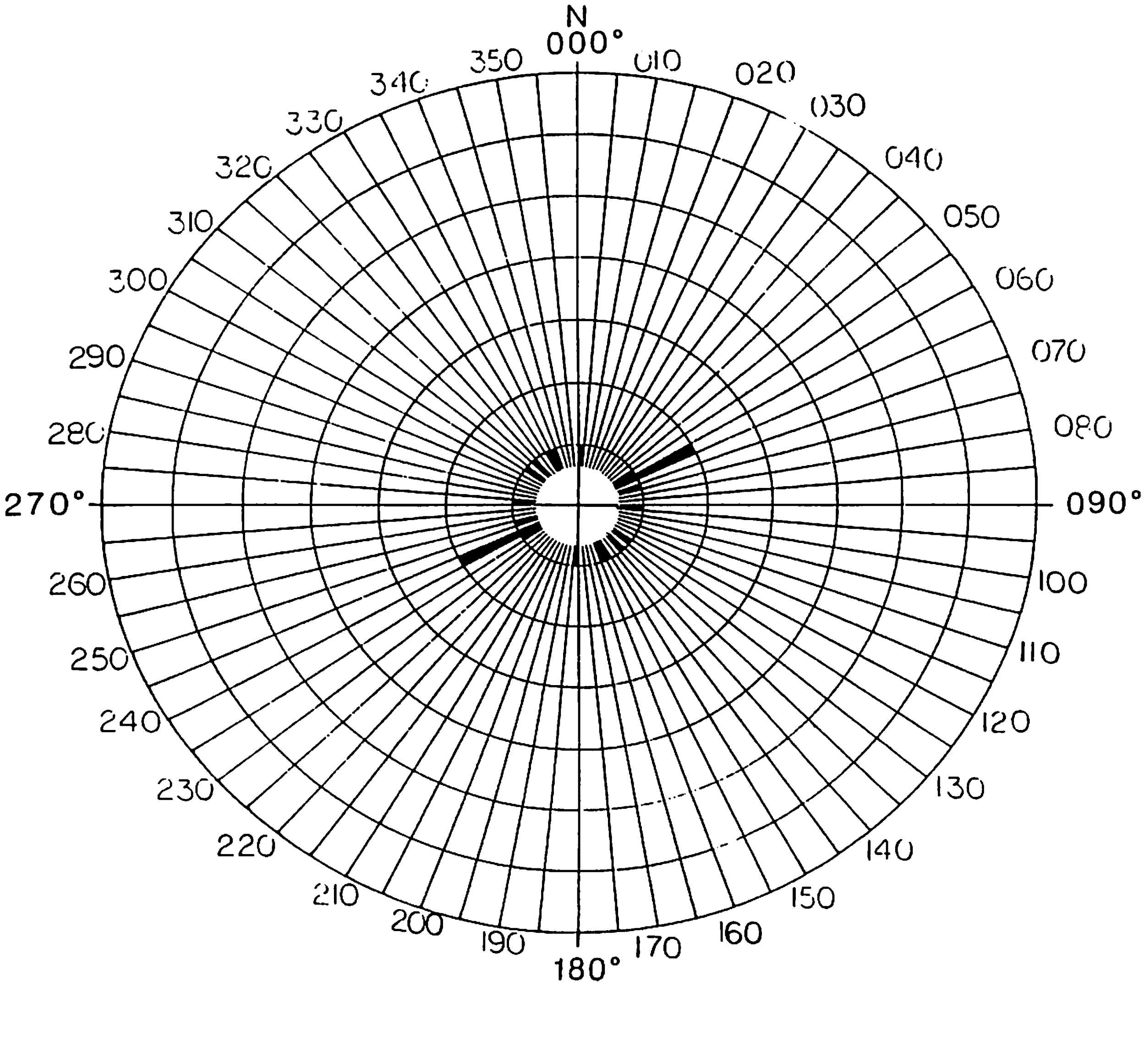


Figure 13. Rose diagram showing the secondary fracture pattern in Vap's Pass Quarry.

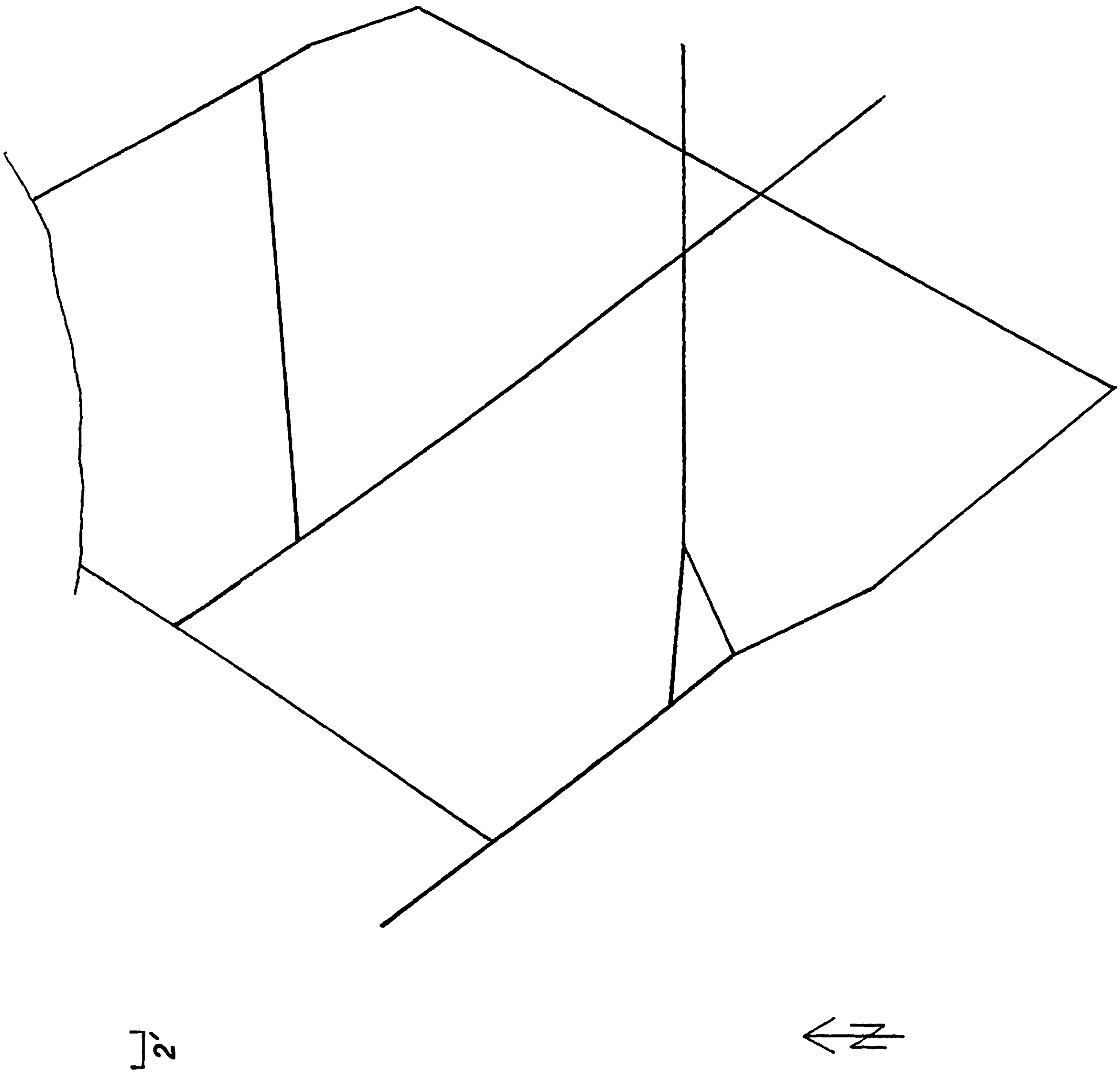
11B). These fracture zones are 2 to 3 feet in width and are comprised of closely spaced fractures that are between one and three inches apart. These zones are more highly visible in the south side of the roadcut than those in the north side. This difference in visibility may simply be a function of the zones in the north side being more intensely weathered than those in the south side. This weathering makes the individual fractures hard to define in the north side which subdues the fracture zone's appearance. The fractures comprising the zones in the south side retain their definition making the zone much more visible.

The fractures that comprise these zones appear to be parallel with the 330 degree fracture set, although the fractures in some of the zones appear to radiate out into the rock face almost like the spokes on a bicycle wheel. The fact that these zones appear to be parallel only to the 330 degrees fracture set may be due to the bias of observing the fractures along the roadcut. Since the roadcut trend is close to being parallel to the 070 to 080 degrees fracture set, these fractures cannot be seen in cross-section in the roadcut.

Uncas Quarry

Figure 14 shows fractures mapped in the Uncas Quarry, at the same scale as the Vap's Pass Quarry. Primary and secondary fractures were again mapped using the same criteria as in the Vap's Pass Quarry. A quick comparison between the map generated in Vap's Pass Quarry and this map will show a definite difference between the fracture geometry in the two quarries. The primary

Figure 14. Map of Fractures at the Uncas Quarry.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fractures show basically the same overall geometry except that they do not exhibit bending along the strike to the degree as the fractures in Vap's Pass. The secondary fractures that are so abundant in Vap's Pass are absent in the mapped area of the Uncas Quarry. This lack of secondary fractures is attributed to two possibilities. First, this quarry has much more detritus covering the bedding surface so that many of the secondary fractures are covered. Second, fractures that fall into the category of the secondary fractures are present within the map area, but they originate from areas that have the appearance of blasting points. Therefore these fractures have not been included on the map.

The Uncas Quarry contains a primary fracture pattern that is dominated by three fracture sets (Figure 15). The most well developed set trends between 320 and 335 degrees. The second set trends between 080 and 100 degrees. These two sets are similar in orientation to the primary fractures in the Vap's Pass Quarry. The third set trends between 010 and 025 degrees and is roughly parallel to the axial surface trace of the Mervine Anticline in this area (Figure 16). The secondary fractures were measured in an area that is adjacent to the mapped area. They show an overall distribution similar to the primary fractures (Figure 17). This similarity in fracture distribution is probably due to the heavy detritus covering this quarry which may have caused measurement of some primary fractures as secondary fractures.

Viewed in the quarry walls, the fractures are mainly normal to bedding with the few exceptions still showing very high angles. The fractures that show a visible gap generally cut across all of the

Figure 15. Photograph showing the upper bedding surface in the Uncas Quarry.

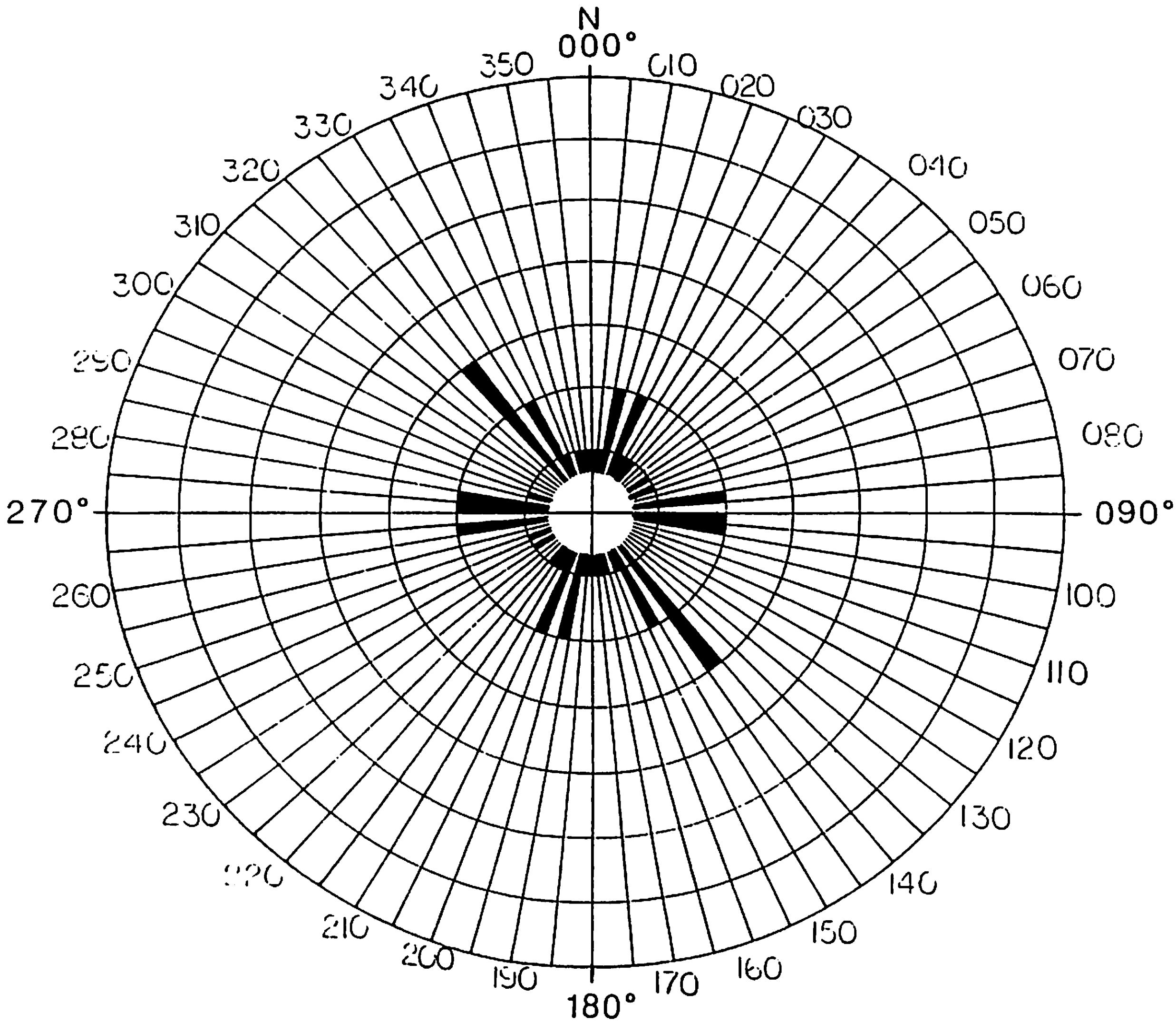

Figure 16. Rose diagram showing the primary fracture pattern in the Uncas Quarry.

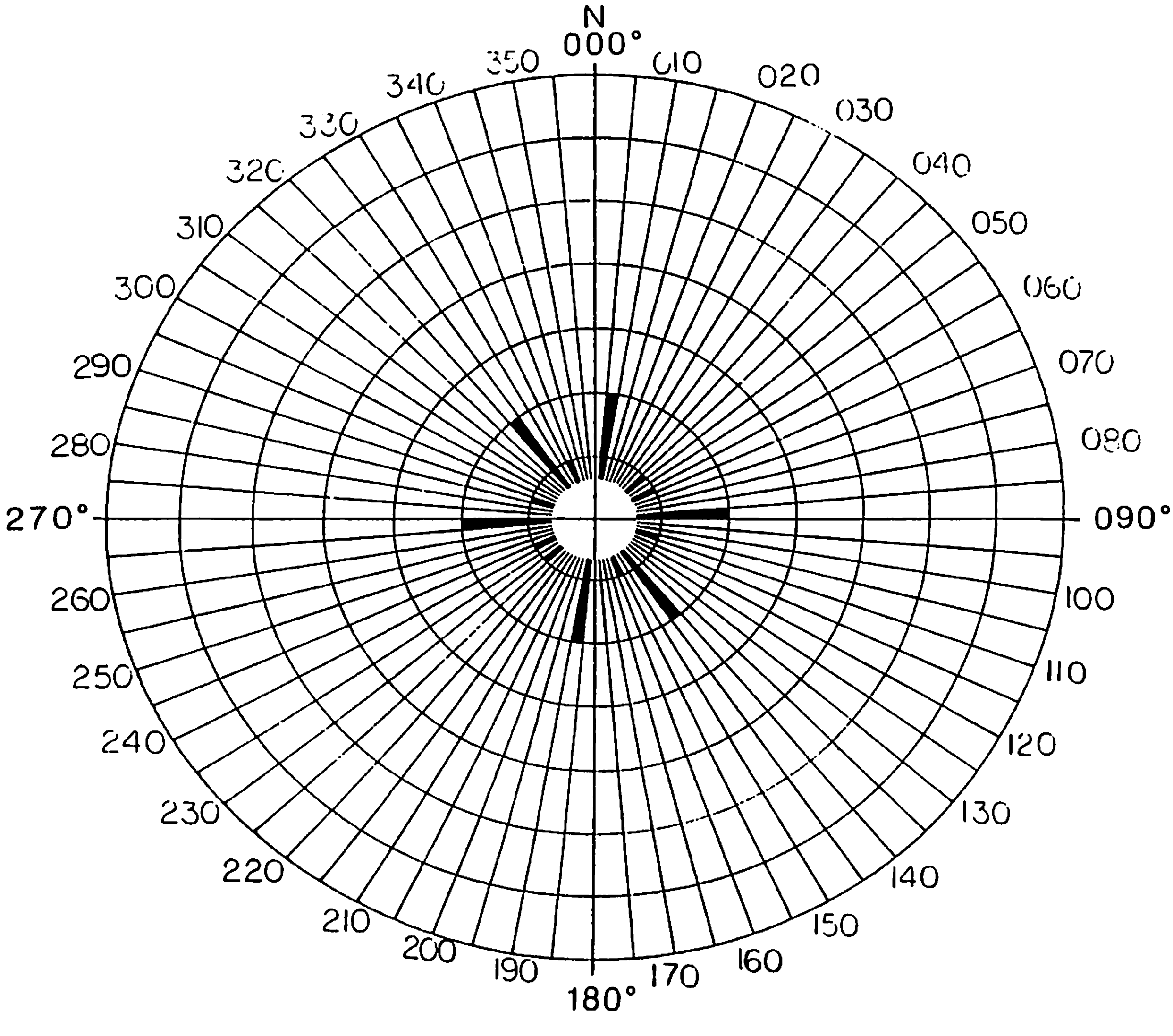

Figure 17. Rose diagram showing the secondary fracture pattern in the Uncas Quarry.

bedding planes while other smaller fractures are contained within individual beds.

The closely spaced fracture zones observed in the Vap's Pass Quarry are also evident in the Uncas Quarry and exhibit the same morphology as those in Vap's' Pass, although some of the zones either narrow or widen at bed boundaries. These fracture zones appear to be parallel to the fracture set trending 080 to 100 degrees. The observation of these fracture zones is also biased by the limitation of only having a surface that trends parallel to the 320 to 335 degrees fracture set in which to view the fractures in cross-section. This makes it impossible to observe the 320 to 335 degrees fracture set in cross-section. Another difference between these zones and those in Vap's Pass is that the zones in the Uncas Quarry are much more subtle and less visible.

Dozer Quarry

As stated earlier, the fracture orientation data in the Dozer Quarry was collected by measuring fractures in the quarry walls. Because the primary and secondary fractures are difficult to differentiate in cross-section, there was no attempt to measure secondary fractures in this area. Additionally, since this quarry is currently active, numerous fractures that can be classified as secondary can be inferred to have been caused by blasting. Therefore, only the fractures that are continuous and cut across the bedding planes were measured. The fractures form an orthogonal fracture system with the individual sets oriented at 320 to 325 degrees and 070 to 080 degrees (Figure 18), similar to the Vap's Pass orientations. The 010 to 025 degrees set that is present in the Uncas Quarry is absent here.

This quarry provides an excellent opportunity to observe both the northeast and northwest trending fractures in cross-section because there are two quarry walls, one parallel the 320 degrees fracture set and the other one parallel to the 070 degrees fracture set. In cross-section, the fracture set trending 070 to 080 degrees is generally normal to the bedding plane. The fracture zones are present in the Dozer Quarry along the fracture set trending 320 to 325 degrees, but they are absent in the 070 to 080 degrees set (Figure 19A). This is the same orientation of the fracture zones as in the Vap's Pass Quarry.

The set trending 320 to 325 degrees is also normal to the bedding plane in most cases, but some of the fractures show dips of 60 to 70 degrees to the east and to the west. These dipping fractures are only evident in the 320 to 325 degrees set and only in this quarry. The common geometry for the occurrence of these fractures is for an east dipping and a west dipping fracture to dip towards each other and for the beds in between to have slight reverse separation (Figure 19B). This geometry is similar to that which Harding (1985) called a positive flower structure. A flower structure forms as a result of strike-slip motion, where the faults which comprise the system converge at depth (Figure 20) (Kearey and Vine, 1990). Bartlett et al. (1981) produced these flower structures in experiments using layers of Indiana Limestone in a strike-slip zone. Although the geometry of fractures in the Dozer

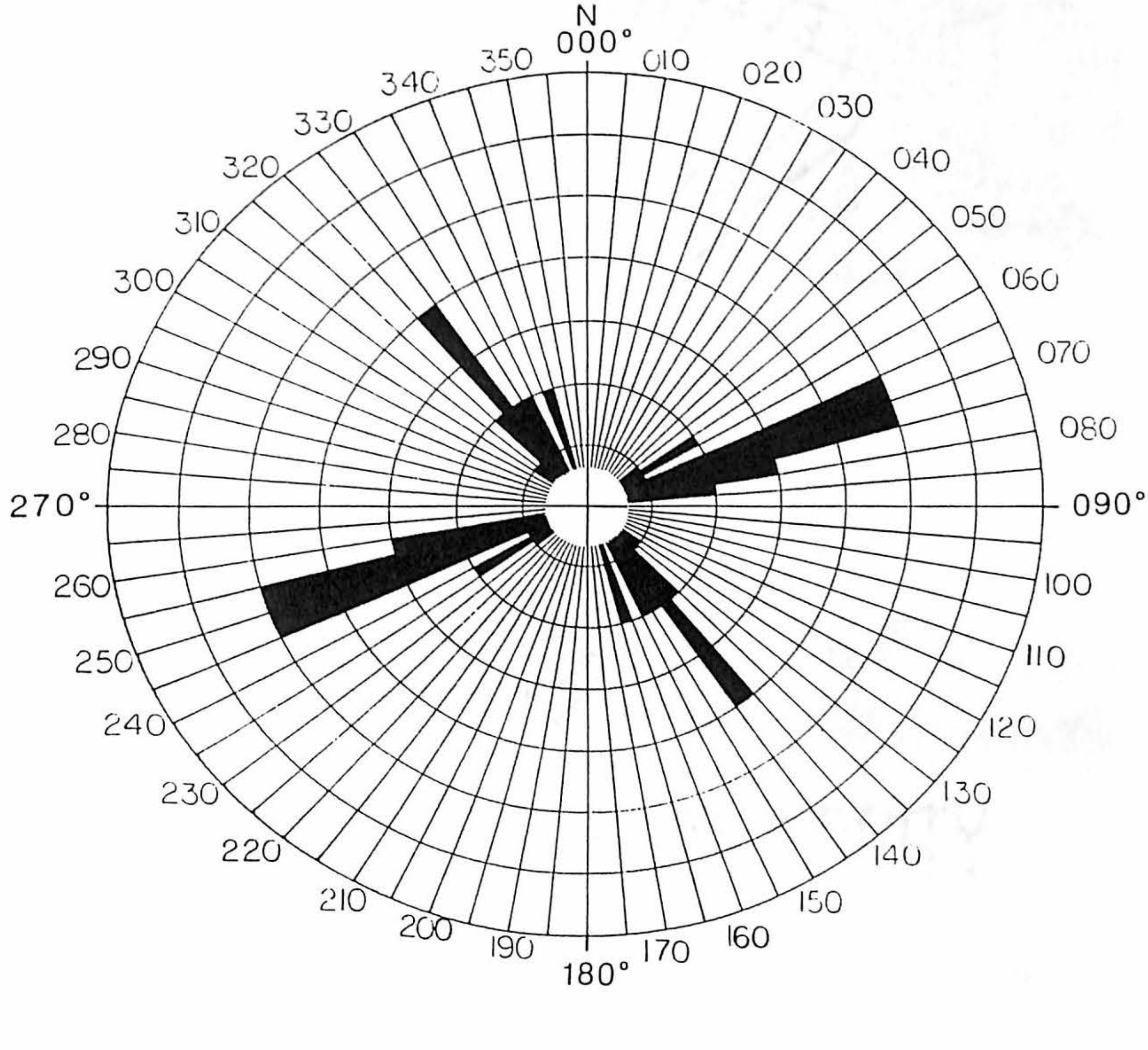

Figure 18. Rose diagram showing the fracture pattern in the Dozer Quarry.

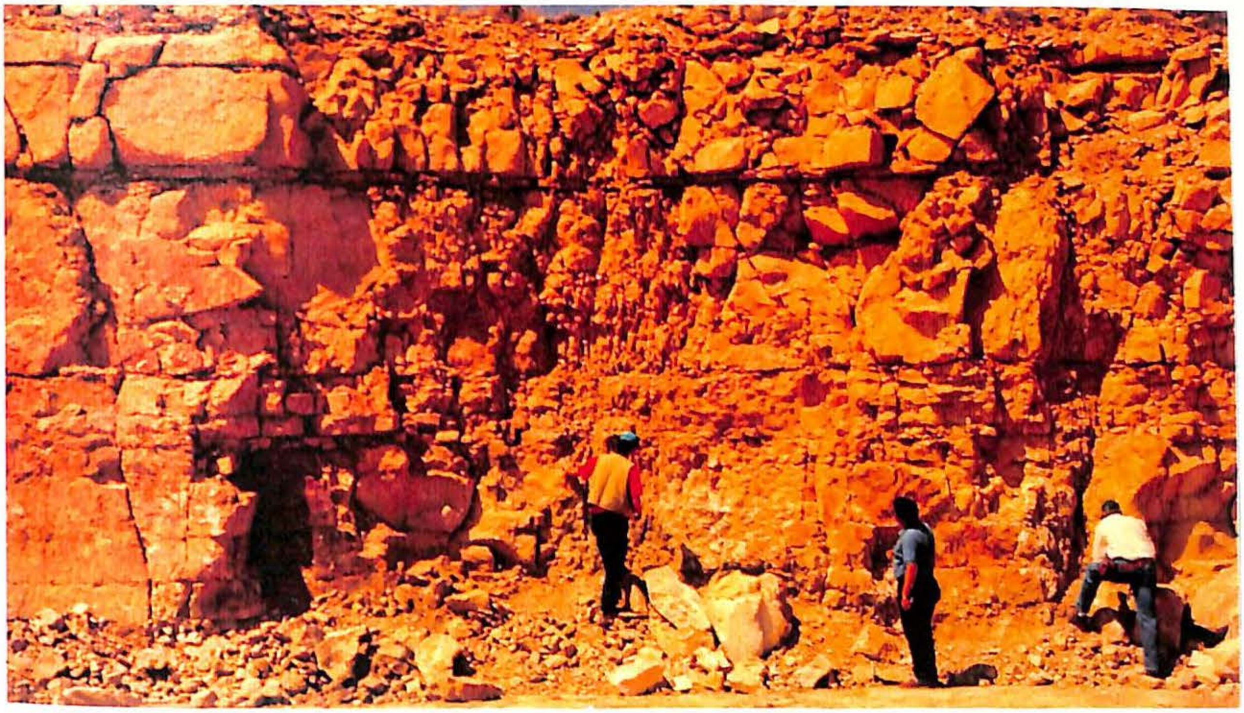

Figure 19. A. Photograph of a fracture zone in the north wall of the quarry.

B. Photograph of the south wall showing reverse separation along the dipping fractures.

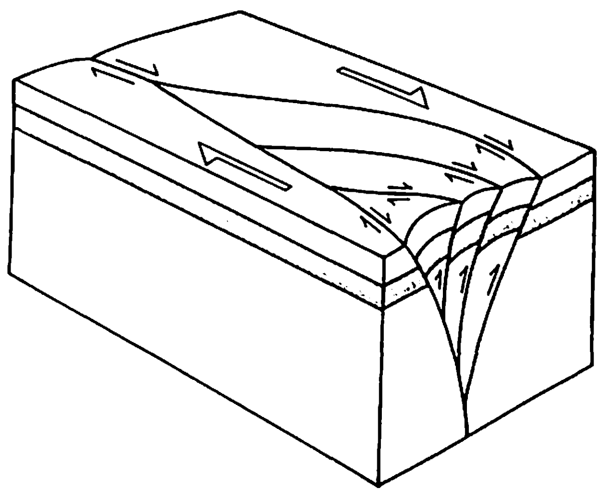

Figure 20. Drawing illustrating a positive flower structure (from Keary and Vine, 1990).

Quarry resembles a flower structure, no other evidence for shearing, i.e. slickensides, has been found on the fracture surfaces .

Mechanisms of Fracturing in the Three Quarries

The fracture geometries in all three quarries are similar with two exceptions, the dipping and curving fractures in the Dozer quarry and the 010 to 025 degrees set in the Uncas Quarry. The geometry indicates that there is a well pronounced orthogonal primary fracture system in all three quarries. The orthogonal sets generally trend 320 to 330 degrees and 070 to 080 degrees. They are usually considered as tensile opening mode fractures formed during a regional uplift.

According to Twiss and Moores (1992) one current theory on the formation of orthogonal joint sets allows for the formation of both sets within the same stress field. As the rocks are uplifted, the stresses that are acting on the rocks will all decrease. The horizontal stresses will decrease at a faster rate than will the vertical stress which is due to overburden. Therefore the maximum compressive stress (σ_1) will be vertical and the minimum compressive stress (σ_3) will be horizontal. Of the two horizontal stresses, one will be the intermediate horizontal stress (σ_2) and the other will be σ_3, which in this case will be an effective tensile stress. The first set of joints will form in the σ_1-σ_2 plane and perpendicular to σ_3.

The formation of these joints will relieve the effective tensile stress normal to these joints, making the other horizontal principle stress the maximum effective tensile stress. The net effect is that the horizontal stresses reverse, in that what was σ_2 will become σ_3 and σ_3 will become σ_2. A second set of joints will then form in the new σ_2-σ_3 plane which will be perpendicular to the first set.

The implications of the dipping fractures are important if they could be interpreted as flower structures. They would suggest that the subsurface fault has experienced strike-slip movement. Since this fault is thought to be related to the Nemaha Ridge, then it is possible that in north central Oklahoma, the Nemaha Ridge itself also experienced strike-slip motion.

However, the orthogonal nature of fractures in all three quarries may not support the strike-slip hypothesis. The 070 to 080 degree fracture set trends subparallel to the maximum horizontal tectonic stress which indicates mode I opening. The 320 to 330 degrees fracture set is perpendicular to the maximum horizontal tectonic stress and therefore also indicates mode I opening.

Therefore it is highly probable that the dipping fractures are also tensile fractures which are bending perpendicular to the topographic plane. Although not well understood, the bending on the topographic plane is well observed in the area (Figure 10). Therefore, the dipping fractures may represent bending along the vertical plane.

The third fracture set in the Uncas Quarry trends 010 to 020 degrees, is subparallel to the axial surface trace of the Mervine anticline and has no counterpart in either of the two other quarries. This suggests that these fractures formed during an event separate from the event that formed the orthogonal fracture sets. They may have been formed in response to tensional forces along the axial trace of the Mervine anticline.

The secondary fracture sets are highly variable in their orientation and appear to have formed as a result of stresses at the outcrop level. These stresses are a result of the compaction of the shale layers which separate the individual limestone beds. The thicker the shale layer, the more compaction it will experience and the greater the flexure of the overlying limestone bed.

CHAPTER V

DIAGENETIC HISTORY AND X-RAY DIFFRACTION

Comparison of Vap's Pass and the GW-3 Core

Thin sections from the GW-3 core were examined for evidence of diagenesis and were compared to thin sections from Vap's Pass Quarry, Dozer Quarry, and the Uncas Quarry. The thin sections from the GW-3 core were stained with Alizarin red and potassium ferricyanide to assist in determining calcite and dolomite. The thin sections that were studied were obtained from Conoco Inc., and are the same thin sections used by Toomey (1992).

The most obvious diagenetic process that has occurred in the Barneston Formation is the dissolution of the carbonate constituents and is present in both the core and outcrop sections. This is evident by the large amount of moldic porosity which occurs throughout the section, but most notably at the base and near the top of the Fort Riley Limestone.

Both the core and all three outcrops have undergone partial silicification of fossil fragments. This process did not affect the uppermost beds of the section and is most evident at the contact between the Florence and Fort Riley Limestones which is the layer of large cannonball chert nodules.

All locations also show evidence of dolomitization. The GW-3 core contains baroque dolomite rhombs which line some open fractures and voids (Figure 21). The presence of this baroque dolomite suggests the movement of hydrothermal fluids through open pathways. The outcrop sections contain only small amounts of baroque dolomite which is probably due to later dissolution.

The original isopachous cement was removed early and was replaced by epigenetic sparry calcite cement. Some skeletal grains also have syntaxial calcite overgrowths. These events appear to have occurred early in the paragenetic sequence. The dissolution and emplacement of the baroque dolomite rhombs occurred as a later event. These samples are also cut by numerous microstylolites which have accumulations of quartz silt, some baroque dolomite, and pyrite (Figure 22). These stylolites are also a late diagenetic event.

A comparison shows that the Barneston Formation at Vap's Pass, Dozer Quarry, Uncas Quarry and the GW-3 core have experienced similar diagenetic histories. All show partial silicification of fossils, *some dolomitization*, dissolution, microstylolites, and replacement by sparry calcite. The outcrops contain less baroque dolomite than is present in the core, which is the only difference between the two locations. Since baroque dolomite is indicative of deep environments and hydrothermal fluids, it is unlikely to be a near-surface event. Therefore the baroque dolomite was probably present at Vap's' Pass and was removed by later dissolution.

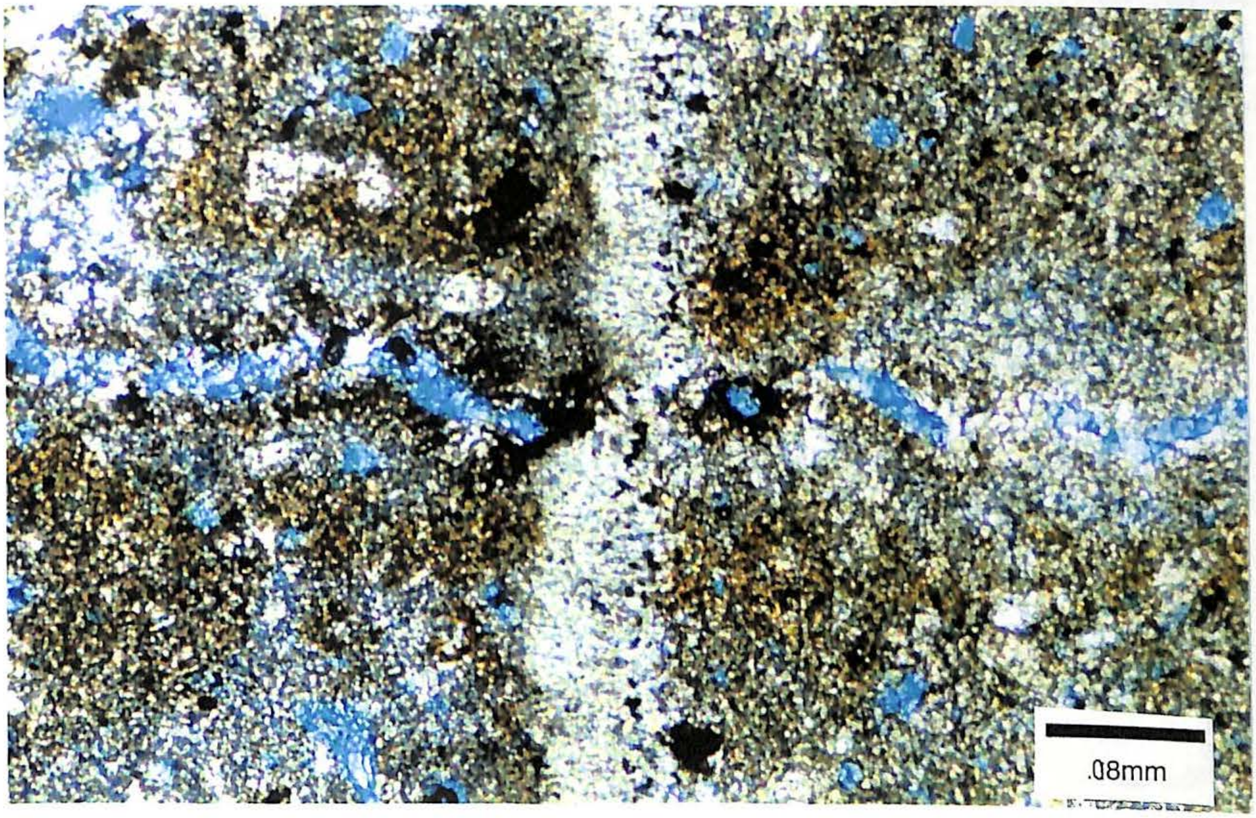

Figure 21. Photograph of a microfracture lined by dolomite.
The microfracture also cuts a fossil.

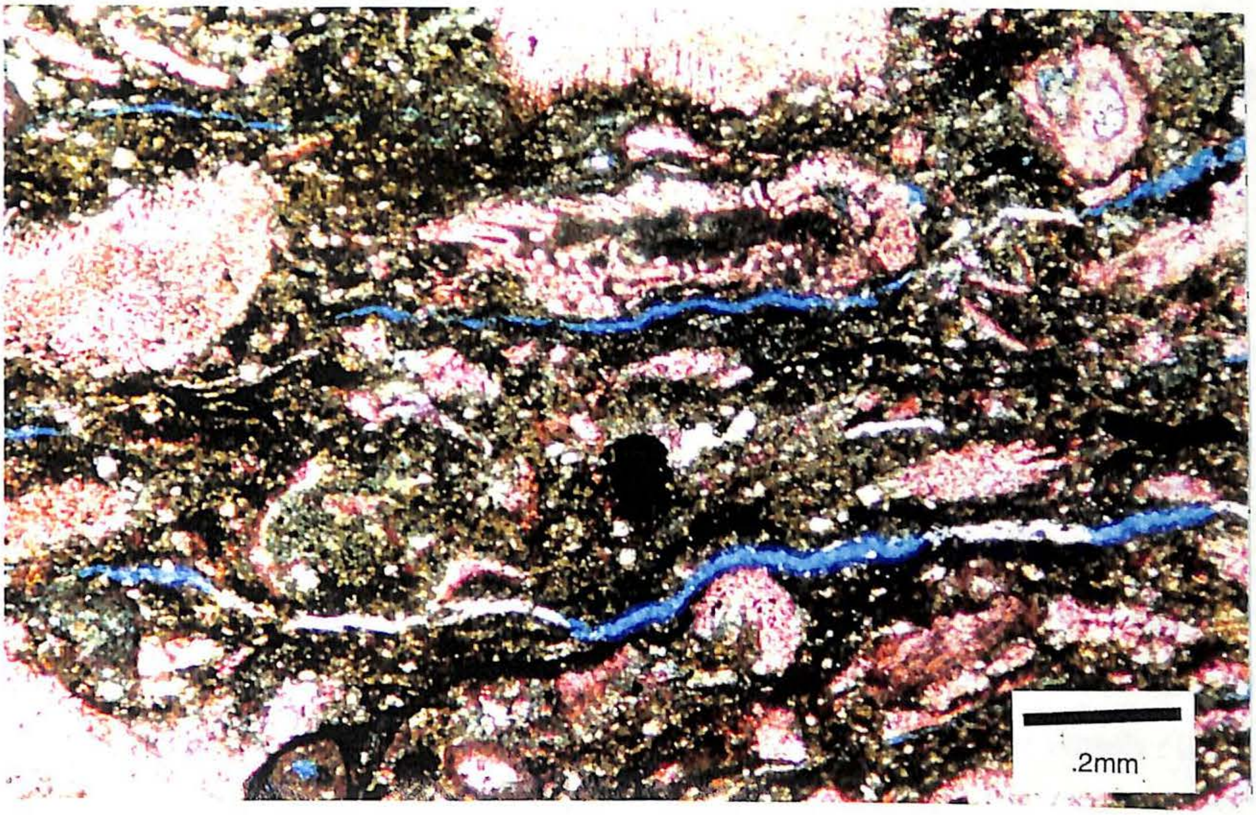

Figure 22. Photograph of a stylolite containing quartz silt, dolomite, and pyrite.

X-Ray Diffraction

Samples of the material that fills some of the fractures in the Dozer Quarry were collected for examination by X-Ray diffraction. This examination was prompted by the geometry of fractures in this quarry and the possibility of strike-slip motion along some of the fractures. If the fractures did undergo shearing, then the material filling the fractures should contain some amount of fault gouge. The purpose of using X-Ray diffraction is to determine the composition of the fracture filling clay.

The samples were collected from various locations within the quarry. Two samples, CL-1 and CL-2, were taken from dipping fractures in the north wall of the quarry (Figure 23) whereas another sample, CL-3, was taken from a dipping fracture in the south wall. One sample, CL-4, was taken from a bedding plane in which a small shale layer separated two beds of limestone. This bedding plane sample was taken as a control sample, since it is not fracture fill, no fault gouge should be present. Also sampled was a piece of limestone located just above the chert layer in order to determine which clays are included in the rock.

The limestone sample was prepared by first crushing the rock into a fine powder. This powder was then washed in acidic acid to remove the carbonate while leaving all non-carbonate material behind. After acid washing, the sample was then washed four to five times with distilled water to remove all of the acid. The suspended particles were then placed on a heated porcelain plate

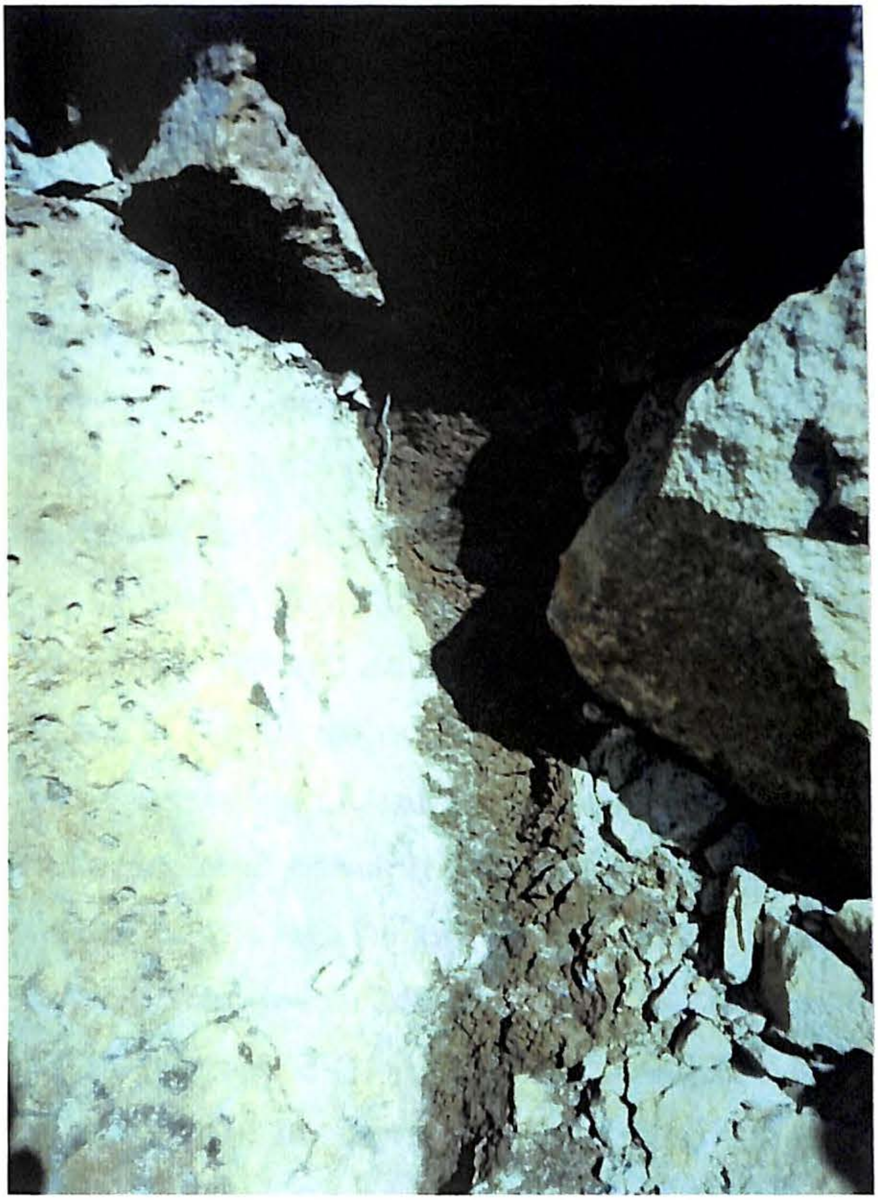

Figure 23. Photograph of fracture filling clay.

and the water was allowed to boil off leaving a thin cake of clay on the plate. The plate was then examined by X-Ray and the results showed the presence of quartz as well as the clays illite and kaolinite. These results are supported by petrographic analysis which showed the presence of silt sized quartz, chert, and void spaces filled by kaolinite and illite.

The fracture filling clay was prepared by adding water until the material was liquefied. The sample was then strained through a sieve to remove any non-clay particles. Acidic acid was not used because of the desire to preserve any calcite that might be present. It is the presence of calcite in the fracture fill that is thought to be diagnostic of shearing along the fractures.

The X-Ray diffraction revealed that the fracture fill from all locations as well as the sample from the bedding plane, had the same general composition. They all contained mixed-layer illite/smectite clays as well as kaolinite and abundant quartz. The one thing that was curiously absent was abundant calcite. Only one sample, CL-1, contained a significant amount of calcite while CL-4 contained a minor amount of calcite. Samples CL-2 and CL-3 contained no calcite at all (Figure 24). In all samples, the level of calcite is well below what would be expected if shearing had taken place.

One major assumption has to be true if this analysis is to be valid. It must be assumed that the material now filling the fractures is the original material. If shearing took place and then the resulting fault gouge had been removed by some agent, then the material now being analyzed would have no genetic relationship with the formation of the fractures. On the other hand, if this is the original

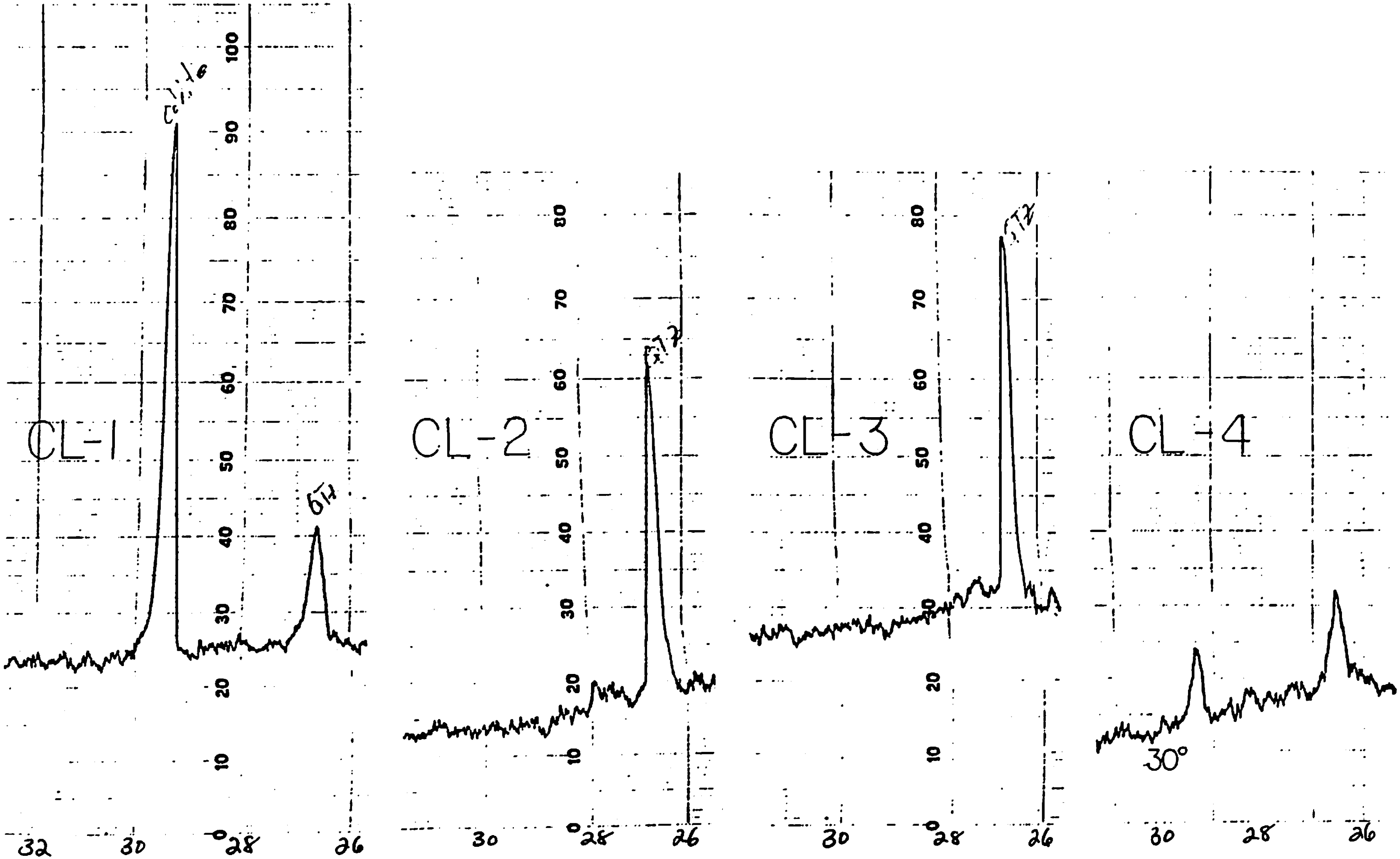

Figure 24. Comparison of the X-ray Diffraction Calcite Peaks From the Four Fracture Fill Samples.

material and shearing had taken place, then some of the limestone rocks must have been powdered and included in the fracture filling clays. If as assumed, the clays are the original fracture filling material, then the absence of calcite can be used as one piece of evidence that no shearing has taken place and the clays filling the fractures have done so after the fractures formed.

CHAPTER VI

CONCLUSIONS

Although the fracture patterns in the study area appear simple at first look, upon closer examination they reveal a complex history of formation. From the data collected during the course of this study, the following conclusions can be made:

1. The lithologic and diagenetic variations are insignificant between the three quarries, therefore any differences in fracture geometry can be attributed to difference in stresses.
2. The orthogonal fracture sets in all three quarries are the result of regional tectonic stresses.
3. The dipping fractures in the Dozer Quarry are probably not the result of wrenching, but possibly the result of vertical bending and hooking.
4. The 010 degrees fracture set in the Uncas Quarry is related to the folding of the Mervine anticline.
5. The lack of the 010 degrees fracture set in the Vap's Pass Quarry is due to its structural positioning on the nose of the Mervine anticline.

6. The lack of the 010 degrees fracture set in the Dozer Quarry is due to the distance separating it from the axial surface trace of the anticline. There is no discernible bending of beds here, therefore the beds can be considered as being effectively flat lying.
7. Fracture zones in the 330 to 335 degrees fracture set are present in the Vap's Pass Quarry and the Dozer Quarry whereas the fracture zones in the 070 to 080 degrees fracture set are present in the Uncas Quarry and the Dozer Quarry.

REFERENCES CITED

Bartlett, W. L., Friedman, M., and Logan, J. M. (1981). Experimental folding and faulting of rocks under confining pressure: Part IV. Wrench faults in limestone layers. Tectonophysics, v. 79, 255-277.

Bates, R. L., and Jackson, J. A., eds. (1987). Glossary of Geology. 3rd ed. Alexandria Va.: American Geological Institute.

Chaplin, J. R. (1988). Lithostratigraphy of Lower Permian rocks in Kay County, north-central Oklahoma, and their stratigraphic relationships to lithic correlatives in Kansas and Nebraska. Special Publication, Society of Exploration Petrologists and Mineralogists, no. 1, 79-111.

Chinsomboon, V. (1976). Surficial geology along the Arkansas valley from Ponca City northward to Kirk's Hill Top, north-central Oklahoma M. S. Thesis, Oklahoma State University: Stillwater.

Clark, G. C., and Cooper, C. L. (1927). Kay, Grant, Garfield, and Noble Counties; in Oil and gas in Oklahoma. Oklahoma Geological Survey Bulletin 40, v. 2, 67-104.

Davis, G. H. (1984a). Structural Geology of Rocks and Regions New York: John Wiley and Sons.

Davis, H. G. (1984b). Wrenching and oil migration, Mervine field area, Kay County, Oklahoma. Shale Shaker, v. 35. no. 1, 1-14.

Dennis, J. G. (1972). Structural Geology. New York: John Wiley and Sons.

Gasteiger, C. M. (1980). Strain analysis of a low amplitude fold in north-central Oklahoma using calcite twin lamellae. M. S. Thesis, University of Oklahoma: Norman.

Goldstein, A., and Marshak, S. (1988). Analysis of Fracture Array Geometry. In S. Marshak and G. Mitra (Eds.), Basic Methods of Structural Geology (pp. 249-67). New Jersey: Prentice Hall.

Harding, T. P. (1985). Seismic characteristics and identification of negative flower structures, positive flower structures, and positive structural inversion. Bulletin of the American Assoc. of Petroleum Geologists, v. 69, no. 4, 582-600.

Harris, J. F., Taylor, G. L., and Walper, J. L. (1960). Relation of Deformational Fractures in Sedimentary Rock to Regional and Local Structures. Bulletin of the American Assoc. of Petroleum Geologists, v. 44, no. 12, 1853-73.

Hobbs, D. W. (1967). The Formation of Tension Joints in Sedimentary Rocks: an Explanation. Geology Magazine v. 104, 550-6.

Hruby, A. J. (1955). Geology of northeastern Kay County, Oklahoma M. S. Thesis, University of Oklahoma: Norman.

Keary, P. and Vine, F. J. (1990). Global Tectonics. Blackwell Scientific Publications: London.

Ladeira, F. L., and Price, N. J. (1981). Relationship Between Fracture Spacing and Bed Thickness. Journal of Structural Geology v. 3, 179-83.

Luza, K. V., and Lawson, J. E. (1981). Seismicity and tectonic relationships of the Nemaha Uplift, part III; Special Publication 81-3. Oklahoma Geological Survey: Norman.

Narr, W., and Suppe, J. (1991). Joint Spacing in Sedimentary Rocks. Journal of Structural Geology v. 13, 1037-48.

Nickelson, R. P., and Hough, V. (1967). Jointing in the Appalachian Plateau of Pennsylvania. Bulletin of the Geologic Society of America, v. 78, 609-30.

Noll, C. R. (1955). Geology of southeastern Kay County, Oklahoma M. S. Thesis, University of Oklahoma: Norman.

Pollard, D.D., and Aydin, A. (1988). Progress in Understanding Jointing Over the Past Century. Bulletin of the Geologic Society of America, v. 100, 1181-1204.

Queen, J. H., and Rizer, W. D. (1990). An integrated study of seismic anisotropy and the natural fracture system at the Conoco Borehole Test Facility, Kay County, Oklahoma. Journal of Geophysical Research v. 95, no. B7, 11255-11273.

Sloss, L. L., ed. (1988). Sedimentary Cover - North American Craton: U. S. in Geology of North America, vol. D-2. Geological Society of America: Boulder, CO.

Smith, E. W. (1954). Subsurface geology of eastern Kay County, Oklahoma; southern Cowley County, Kansas, Shale Shaker, v. 5, no. 9, 5-12, 14-17, 19-21, 24.

Toomey, D. F. (1992). Microfacies correlation of the Early Permian Barneston Limestone, Conoco Test Facility to Vap's Pass, Kay County, northern Oklahoma; in Special Papers in Paleontology and Stratigraphy: a Tribute to Thomas W. Amsden, Oklahoma Geological Survey Bulletin 145, 193-219.

Twiss, R. J., and Moores, E. M. (1992). Structural Geology New York: W. H. Freeman and Company.

Woodworth, J. B. (1896). On the fracture system of joints, with remarks on certain great fractures. Boston Society of Natural Historical Proceedings, v. 27, 163-183.

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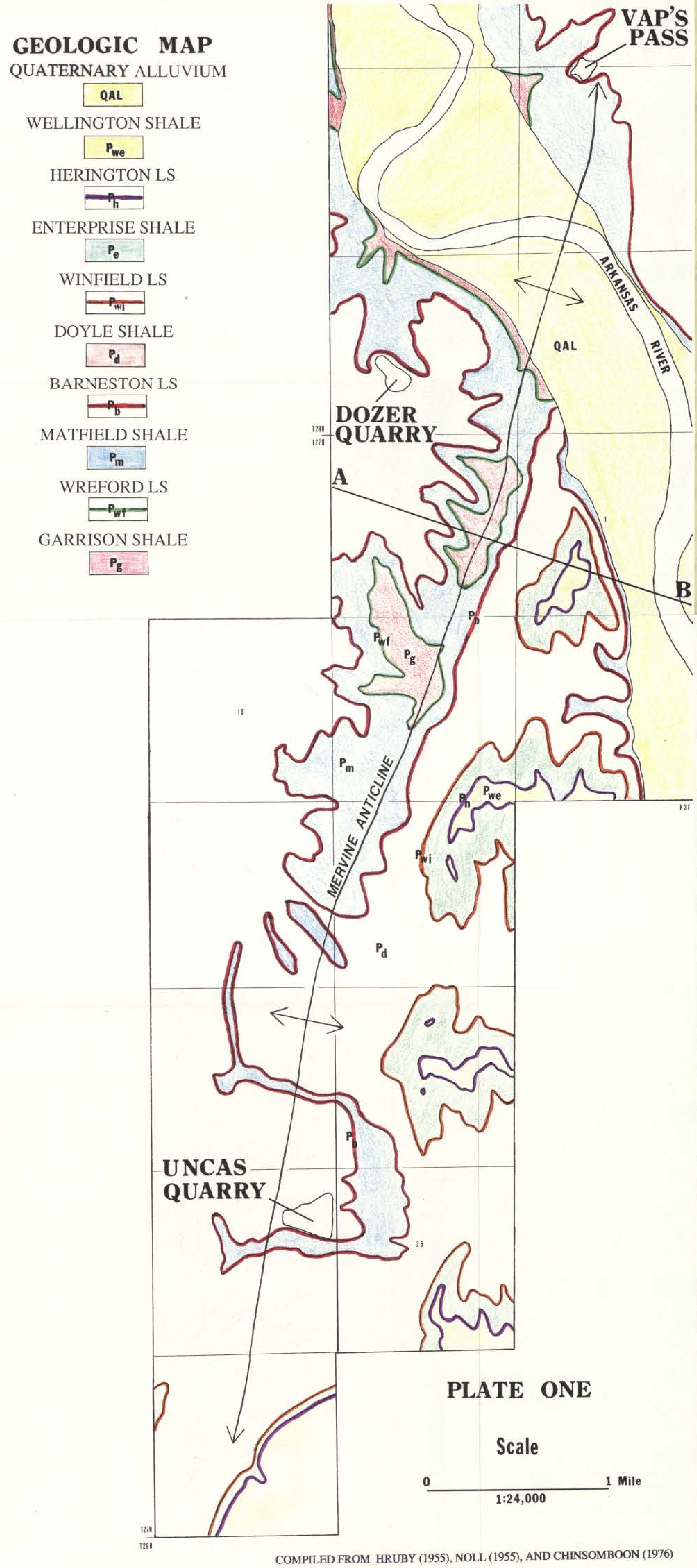

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