AN ABSTRACT OF THE THESIS OF

Richelle A. Krueger for the Master of Science Degree in Physical Science presented on April 28, 1993.

Title: Chert Gravel and Drainage Development in Chase County and Paleodrainage Patterns of the Old Osage River in Eastern Kansas

Abstract Approved: James S. Aber

Committee Members: Dr. James S. Aber, Chairperson

Professor Paul L. Johnston

Dr. David Edds

This study involved two major themes: 1. the study of drainage development and upland chert gravels in Chase County; 2. the addition of Olpe Soil/chert gravel sites in Chase, Neosho, and Wilson Counties to the existing KS-CHERT database. Maps created to study drainage development and upland chert gravels in Chase County include the following: areal extent of chert gravels in Chase County; elevation of chert gravels in Chase County; orientation of stream valley lineaments compared to subsurface fractures in Chase County; digital elevation model of Cottonwood Limestone in Chase County. An updated KS-CHERT map indicating the distribution and elevation of chert gravel deposits in eastern Kansas was also developed for further study of the paleodrainage patterns of the Neogene Old Osage River and its tributaries.

The IDRISI geographic information system was used in the production of all maps. Analysis of maps created for the study of drainage development and chert gravels in Chase County seems to indicate a positive correlation between structural elements in the county and drainage development. Examination of the updated KS-CHERT database suggests: the main stem of the Old Osage River flowed eastward across southern Chase and Lyon Counties toward southern Coffey County, where it joined a tributary whose route paralleled the route of the modern Cottonwood and Neosho Rivers; the Old Osage River exited the state in a manner similar to the modern Neosho River; a northern stream or tributary of the Old Osage River may have joined with the main stem of the Old Osage in the vicinity of southwestern Anderson County or northwestern Allen County.

The information concerning the location and coverage of Olpe Soil/upland chert gravel may aid in determining alternative sources of gravel for roads that would not disturb the habitat of the threatened Neosho madtom. The Neosho madtom is a small catfish that predominantly inhabits chert gravel bars in the Cottonwood and Neosho Rivers. Its habitat has been threatened by the dredging of gravels in these rivers.

CHERT GRAVEL AND DRAINAGE DEVELOPMENT

IN CHASE COUNTY AND

PALEODRAINAGE PATTERNS OF THE OLD OSAGE RIVER

IN EASTERN KANSAS

A Thesis

Presented to

the Physical Science Division

EMPORIA STATE UNIVERSITY

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

By

Richelle A. Krueger

May 1993

James S. Ager

Approved for the Major Division

Faye N. Vowell

Approved for the Graduate Council

ACKNOWLEDGEMENTS

I wish to extend sincere gratitude to the following:

To Dr. James Aber, for interesting me in researching chert gravels and drainage development in eastern Kansas. He was always available for advice and challenging me to do my best.

To Professor Paul Johnston, for answering a letter sixteen years ago from a high school sophomore inquiring into the Earth Science Program at Emporia State University. He has been an inspirational teacher to many students, and his encouragement through the years is sincerely appreciated.

To Dr. David Edds, for his advice and time in preparing this thesis. His assistance is truly appreciated.

To Emporia State University, for granting me a graduate teaching assistantship. The experience has been invaluable.

A special thanks to my husband Roy for his encouragement and support of my education (I couldn't have done this without you!), and to my children, Katie, Breanna, and Joe, for their eternal patience.

A sincere thanks also to my parents and sister for their encouragement of my education through the years.

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CHAPTER 1. GENERAL SETTING

Introduction:

Mention of the surface geology of eastern Kansas brings the classic Pennsylvanian and Permian cyclothems of the area to mind for many geologists. However, the late Tertiary/early Quaternary gravel deposits, which drape the surface of many upland areas of eastern Kansas, have an equally interesting history, although they have not received the same degree of attention. These upland chert gravels reveal information about the drainage pattern of eastern Kansas during the past few million years by their positions with respect to modern drainage systems and by their content of exotic pebbles, which in some cases suggest sediment sources that differ from modern sediment sources.

Of particular interest are the hill-top and high-terrace gravel deposits of the Neosho, Verdigris and Marais des Cygnes drainage basins (Fig. 1). Although the gravels are composed primarily of chert derived from local Permian bedrock, several hundred exotic pebbles have been discovered, which suggests an origin beyond the Flint Hills (Aber 1985). These exotics led Aber (1985) to propose the existence of an ancient river, which he named the "Old Osage River," whose main stem can be traced through the quartzite-bearing upland gravel deposits of Chase, Lyon, Coffey and Anderson Counties (Fig. 2). The mineralogy of the quartzite exotics indicates that the headwaters of this river may have been located in the High Plains of western Kansas (Aber 1988). The specific source of some of the quartzites may have been

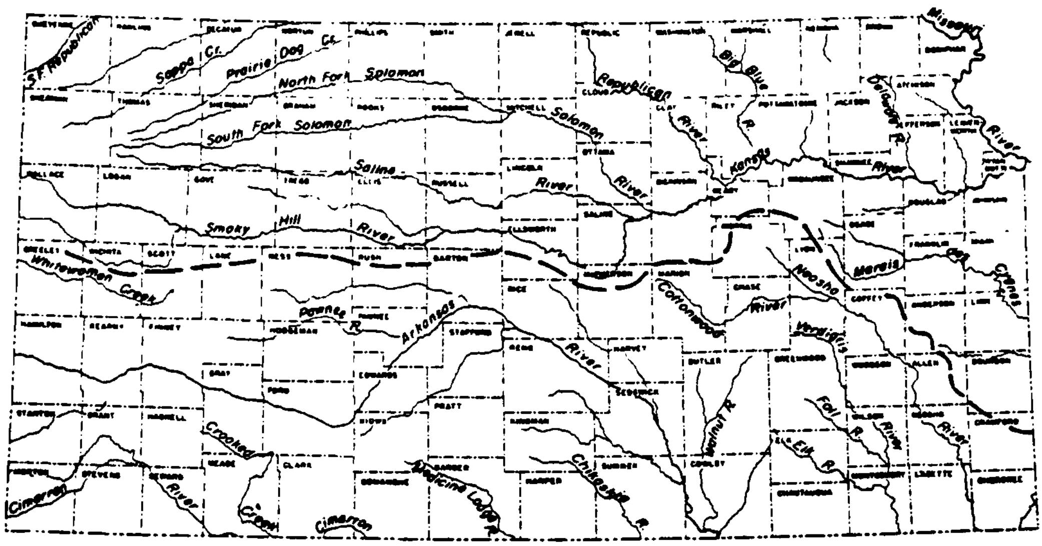

Figure 1. Map showing the major drainage basins of Kansas. Dashed line shows the drainage divide between the Missouri and Arkansas basins. Taken from Aber (1992, figure 1).

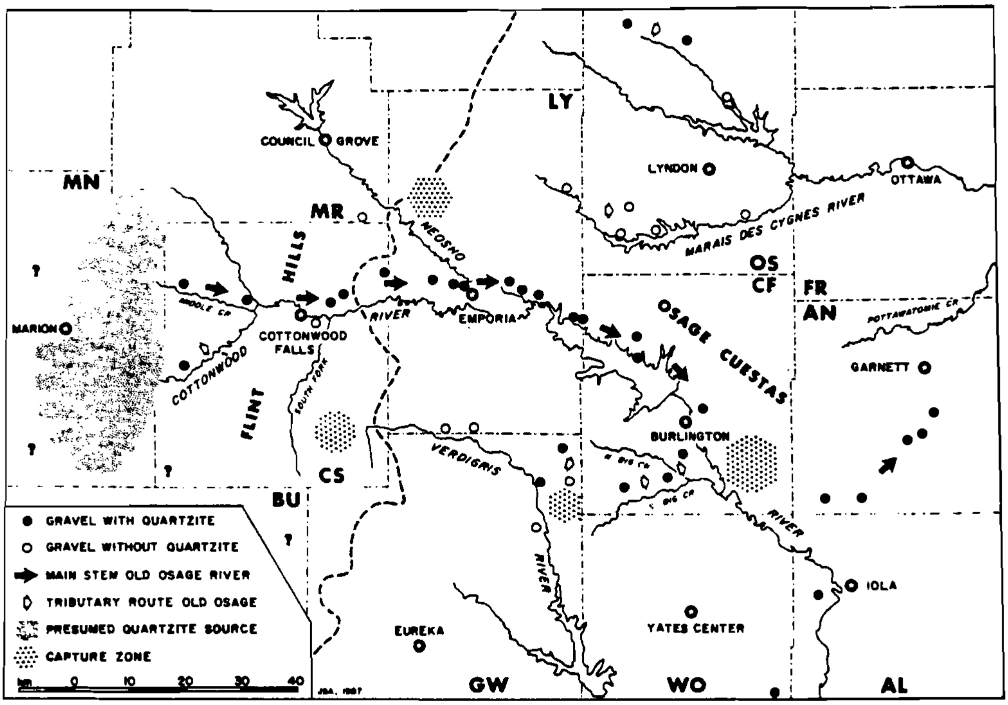

Figure 2. Map showing the distribution of upland chert gravels and drainage features in east-central Kansas. Taken from Aber and Johnston (1990, figure 4-8).

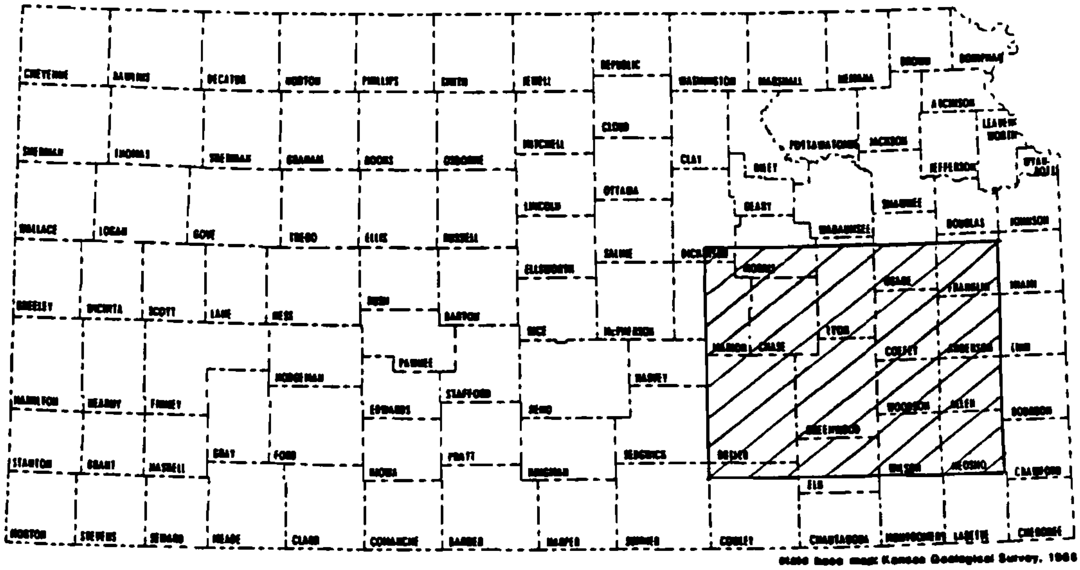

Figure 3. Areal extent of KS-CHERT database.

from the Ogallala Formation, which is a vast apron of unconsolidated sediment that was deposited from Rocky Mountain sources after the Larimide Orogeny of the Miocene.

The route of this river has been traced and recorded on the KS-CHERT database. This raster-structured computer database is composed of a 180-row by 226-column grid in which each cell represents a quarter section of land. The database includes an area of approximately 26,000 square km (10,000 square miles) (Fig. 3).

Part of the purpose of this study was to complete the KS-CHERT database by locating the upland gravels in Chase, Wilson, and Neosho counties. The addition of these counties to the database allowed for a more complete picture of paleodrainage patterns of the area during the past few million years. A more detailed study was conducted on drainage development in Chase County (Fig. 4), with five maps created:

1. A chert gravel map showing location and approximate areal coverage of hill-top and high-terrace gravels.
2. A chert gravel map showing the elevation and location of upland chert gravels in the county.
3. A lineament map of stream valleys in Chase County.
4. A map comparing subsurface fractures to modern drainage patterns in Chase County.
5. A map of Cottonwood Limestone elevations showing areas where bedrock has been deformed.

These maps focus attention on the relationship of subsurface fractures to drainage development in Chase County.

Physiography:

The study area lies primarily in the Osage Cuestas with the western portion located in the Flint Hills Uplands (Fig. 5). Both provinces are a part of the Osage Plains (Fig. 6) which are in turn a part of the Central Interior Lowlands physiographic division. The Osage Plains, which extend southwesterly from the glacial limit of northeastern Kansas into central Oklahoma and northern Texas, have a regional surface slope eastward from western elevations of approximately 400-550 m to eastern elevations between 150 and 200 m (Madole et al. 1991).

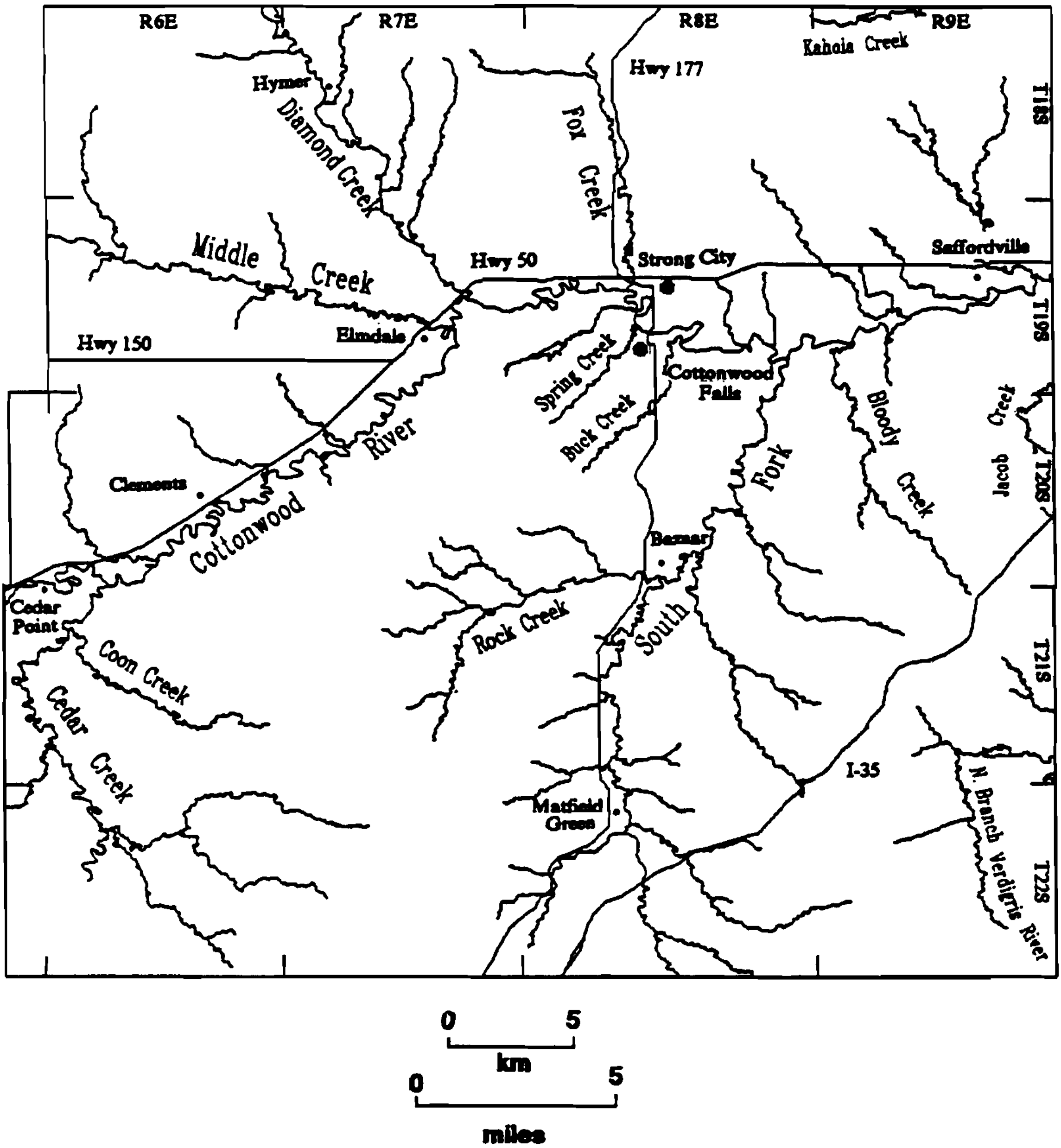

Figure 4. Map of Chase County, Kansas. Streams and roads digitized from 1:100,000-scale topographic map of Chase County published in 1991 by the United States Geological Survey.

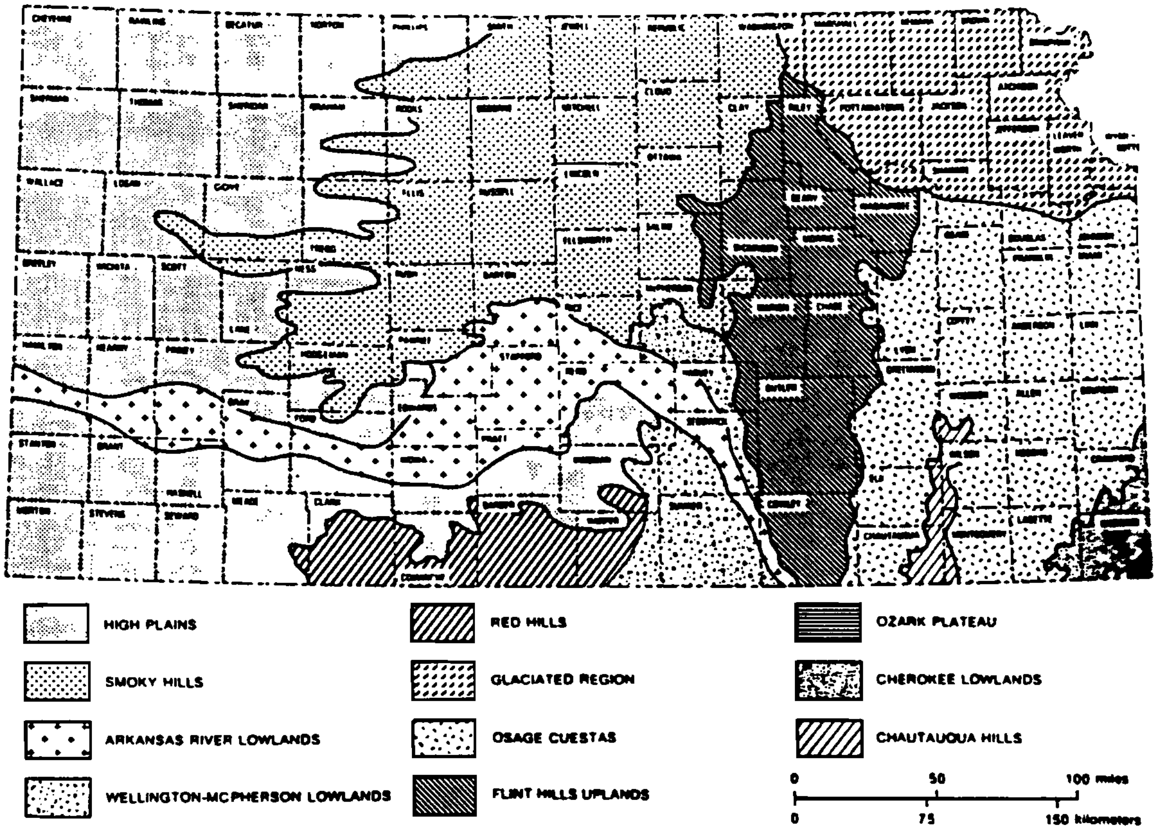

Figure 5. Physiographic map of Kansas. Taken from Buchanan and McCauley (1987, p. 12).

Figure 6. Major physiographic divisions of the south-central United States. Taken from Madole et al. (1991, figure 2.).

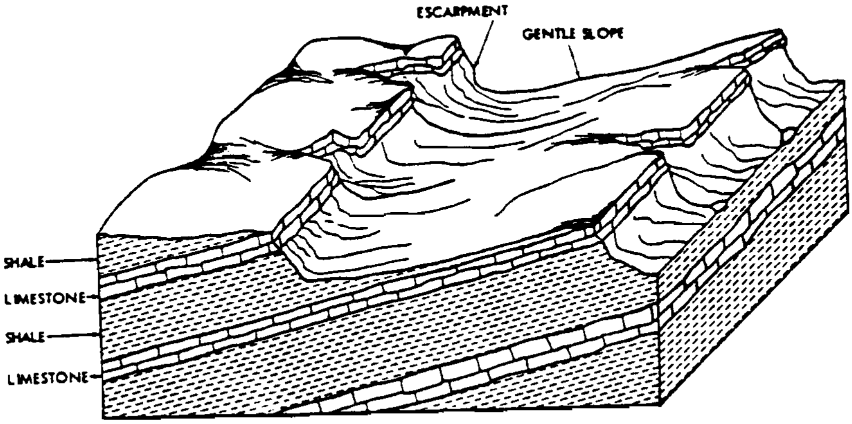

Figure 7. Cuesta topography characteristic of eastern Kansas. Taken from Buchanan and McCauley (1987 p. 321).

Despite the eastward surface slope, the bedrock of the region dips gently to the west. This westward-dipping bedrock, composed of interbedded shales, sandstones and resistant limestones, forms the cuesta topography characteristic of eastern Kansas. Cuestas, a Spanish word for hill or slope (Buchanan and McCauley 1987), have western slopes that dip gently toward the west and steep eastern faces (termed escarpments) composed primarily of resistant limestones (Fig. 7).

Escarpments form the Flint Hills Uplands, which dominate most of Chase County. The Cottonwood and Verdigris River valleys comprise the remaining portion of the county (Neill 1974). The Cottonwood River and its tributaries drain the majority of the county with the exception of approximately two townships in the southeastern portion , which are drained by the Verdigris River (Fig. 4).

Surface Geology:

The surficial geology of the region is composed primarily of interbedded Upper Pennsylvanian and Lower Permian limestones, shales and sandstones that dip gently to the west. Tertiary and Quaternary alluvial gravels are also found, along with Quaternary loess deposits.

The majority of surface limestones and shales in Chase County belong to the Chase and Council Grove Groups of the Lower Permian Series (Fig. 8). However, there are some limestones and shales of the Admire Group exposed along the North Branch of the Verdigris, Jacob Creek and along the northern and southern sides of the Cottonwood River Valley just west of the Lyon-Chase County border.

Quaternary alluvial deposits of gravel, sand, silt and clay as much as 20 m (60 feet) in thickness fill the valleys of the Cottonwood River, South Fork of the Cottonwood River, and Diamond Creek, with thinner accumulations in smaller stream valleys (Moore et al. 1951). There are also alluvial terrace deposits of gravel, sand, silt and clay which are thought to range in age from Tertiary to Pleistocene and were mapped together as an undifferentiated unit (Moore et al. 1951). The younger Pleistocene deposits are generally 3 to 6 m (10 to 20 feet) higher than the modern floodplain. In places where they rest on shales, the deposits lie on an eroded surface which is almost as low as the modern floodplain (Moore et al. 1951).

These younger Pleistocene deposits are primarily developed along the northern side of the Cottonwood River valley and the western side of the South Fork of the Cottonwood River, where they are called the Emporia Terrace.

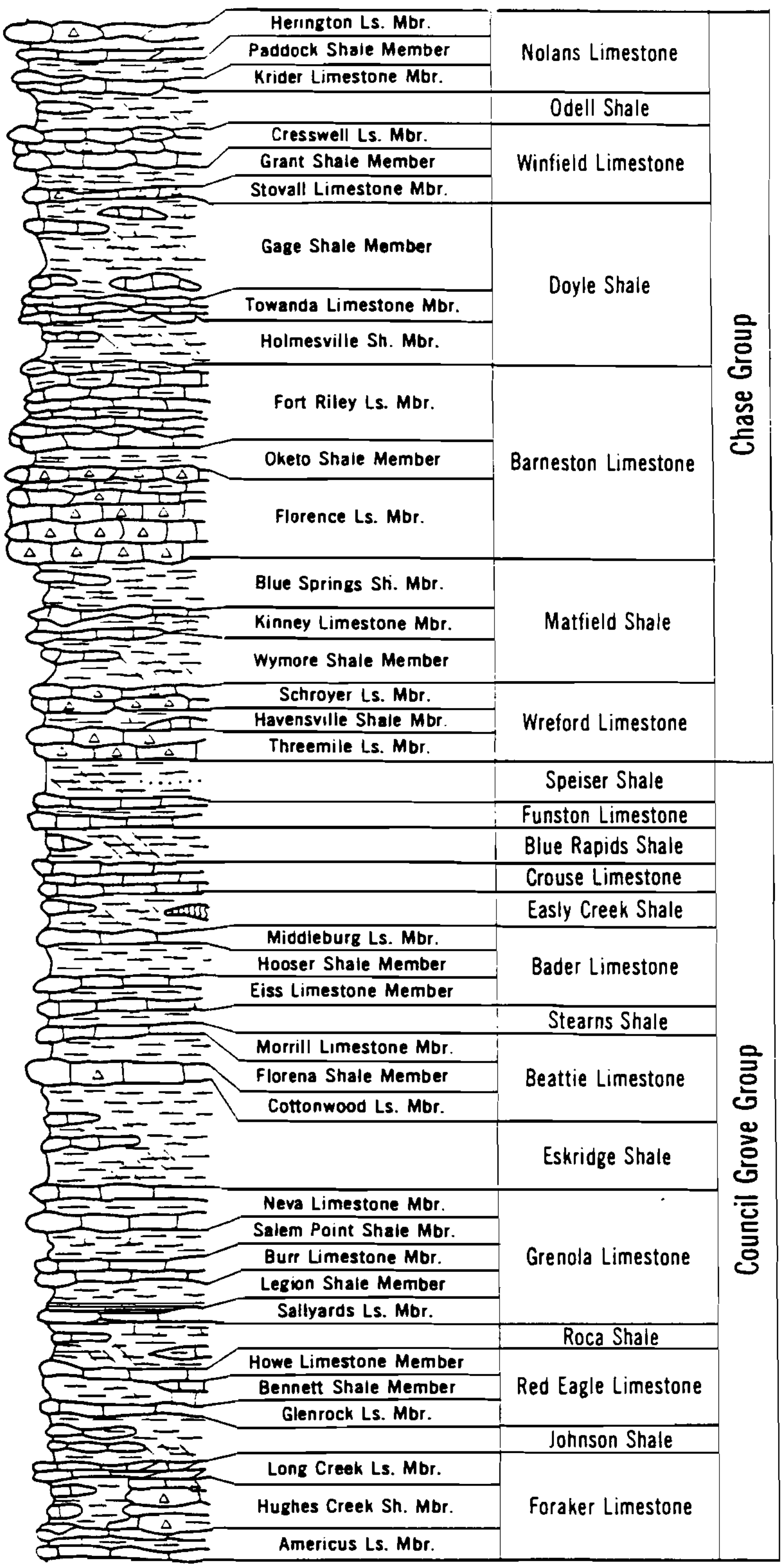

Figure 8. Major rock units of Chase County. The Florence and Wreford Limestones are the primary sources of chert gravel. Adapted from Zeller (1968).

Mid-Pleistocene vertebrate remains as well as supposed Pearlette volcanic ash have been found beneath the Emporia Terrace in Lyon County (Moore et al. 1951). A deposit in the lower part of the Emporia Terrace, located in NE1/4, SW1/4, sec.10, T19S, R9E in Chase County, was described by Moore et al. (1951) as follows:

> "It consists chiefly of coarse subrounded to subangular chert gravel, one-quarter to 3 inches (0.6-8 cm) in diameter. There is an intermingling of chert and quartz sand and a minor amount of silt and clay. The sorting is poor. This predominantly coarse material, which ranges in thickness from a few inches to about 15 feet (5 m), grades upward into tan and buff sandy silt, overlain by tan, buff, or reddish-brown silt and clay. The thickness of the finer material above the gravel ranges from a few inches to about 20 feet (6 m). Locally, various amounts of silt and clay have been removed and, except in the thicker deposits, calcareous matter has been leached."

Terrace deposits, which range from 15 to over 45 m (50-150 feet) in elevation above the modern floodplain, are found along many streams in Chase County and are thought to be Pliocene in age (Moore et al. 1951). These deposits are composed primarily of chert gravel derived from the cherty Permian limestones in the county (Moore et al. 1951). However, well-rounded quartzite pebbles have been found, which suggests a sediment source possibly as far west as the High Plains (Aber 1985).

Terrace chert gravel deposits have economic value as surfacing material for roads, although another source of gravel for roads in Chase and Lyon Counties has come from the dredging of gravel bars in the Cottonwood and Neosho Rivers. A controversy has developed over the dredging of gravels from these rivers due to the disruption of Neosho madtom habitat. The Neosho madtom is a threatened catfish that primarily inhabits the chert gravel bars of the Cottonwood and Neosho Rivers. The disruption of madtom habitat led state officials in 1990 to halt further gravel dredging in the rivers until further research can determine the effects of dredging on the madtom population. A partial solution to the problem may be the development of upland terrace gravel deposits as an alternative source of gravel.

Subsurface Geology:

The subsurface structure of the Osage Plains includes such features as the Salina Basin, the Sedgwick Basin, the Nemaha Ridge, the Forest City Basin, and the Cherokee Basin, which were formed in their present configuration during the Ouachita Orogeny of the Pennsylvanian Period (Fig. 9).

Chase County is intersected by three major tectonic zones: the Fall River tectonic zone which trends northwest, the Nemaha tectonic zone which trends north-northeast, and the Humboldt fault zone which flanks the east side of the Nemaha uplift (Fig. 10). The Fall River tectonic zone is transverse to the 1,100 million-year-old Central North American rift system while the Nemaha tectonic zone marks the eastern edge of the Central North American rift system (Berendsen and Blair 1986). These tectonic zones are thought to be the result of reactivation of pre-existing basement structures during the Ouachita Orogeny of Oklahoma and Arkansas and are recorded in strata overlying the pre-existing basement fractures (Berendsen and Blair 1986).

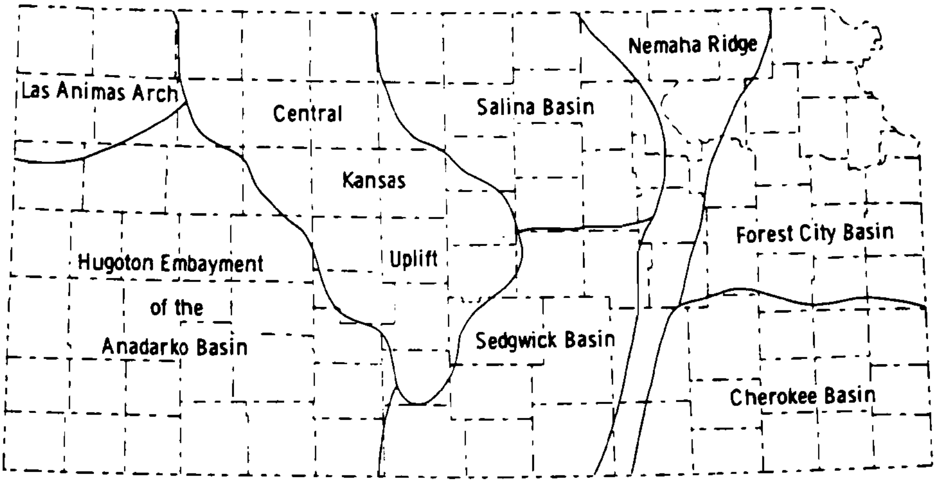

Figure 9. Major subsurface structures of Kansas. Taken From Buchanan and McCauley (1987, p. 14).

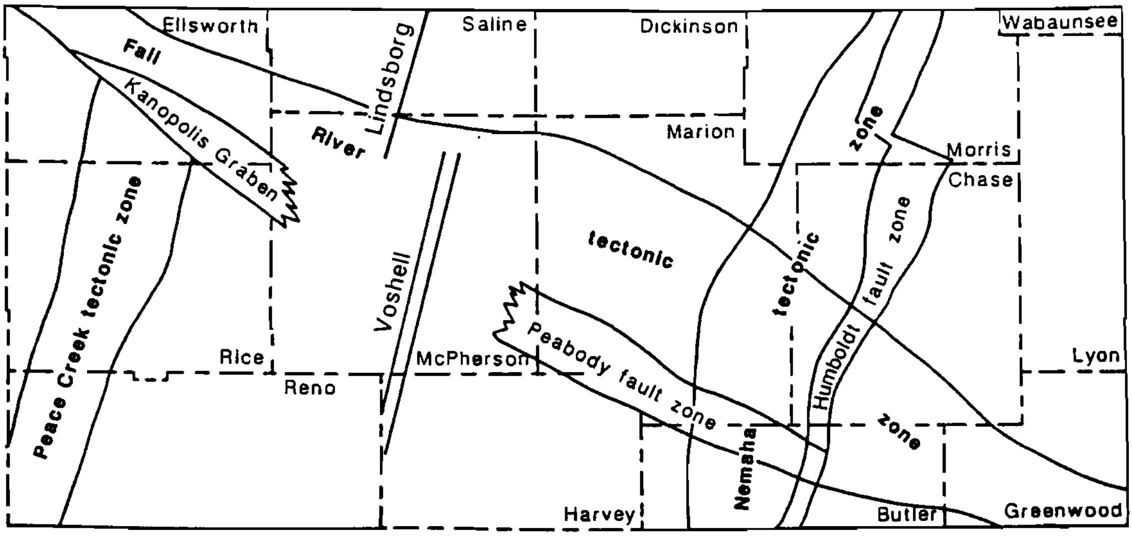

Figure 10. Major tectonic zones which intersect Chase County. Taken from Berendsen and Blair (1986, figure 2).

The Nemaha tectonic zone includes the Nemaha ridge, which extends from Nebraska to Oklahoma. The tectonic zone is a complex system composed of the following: folds; high-angle normal, reverse and strike-slip faults; basement-cored, faulted anticlines; and pull-apart grabens (Berendsen and Blair 1986). In higher portions of the zone in northern and southwestern Chase County, Pennsylvanian rocks lie directly on Precambrian rocks (O'Connor et al. 1951). The Humboldt fault zone also contains a complex series of high-angle sinistral strike-slip faults in which major faults strike primarily north-northeast and transverse faults strike west-northwest. Pull-apart basins developed at the intersections of these faults.

Specific structures in Chase County have been mapped by Berendsen and Blair (Figs. 11 and 12) and include : 1. Elmdale dome, which is located along the crest of the Nemaha uplift just north of the intersection of the Fall River tectonic zone and the Nemaha uplift, 2. Cedar Creek syncline which is a north-northeast trending graben-like feature that straddles the Nemaha uplift, 3. northwest-trending Elmdale fault, which separates the Cedar Creek syncline from the Elmdale dome, 4. Cedar Creek fault, which trends northwest and bisects the Cedar Creek syncline and separates several fault blocks.

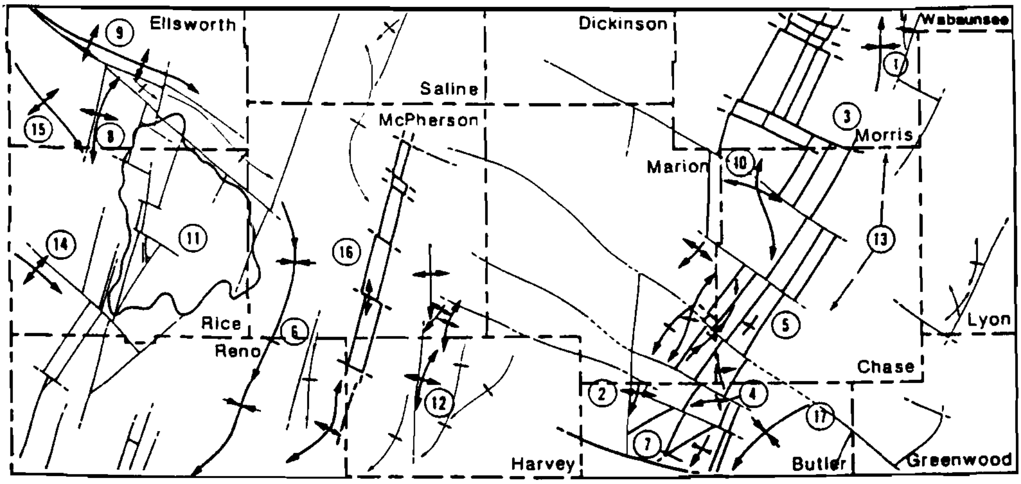

Figure 11. Map showing previously recognized structures in Chase County and surrounding counties. Features of interest in Chase County are: 5. - Cedar Creek syncline, 10. - Elmdale dome, 13. - Humboldt fault. Taken from Berendsen and Blair (1986, figure 3).

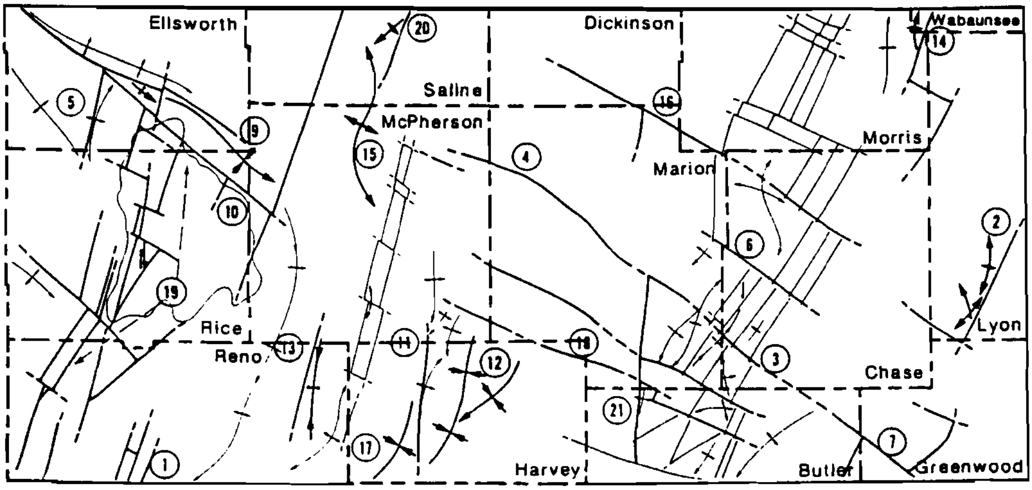

Figure 12. Map showing additional structures identified by Berendsen and Blair in Chase County and surrounding areas. Structures of interest in Chase County are: 3. - Cedar Creek fault, 6. - Elmdale fault. Taken from Berendsen and Blair (1986, figure 4).

* * * * * *

CHAPTER 2. PREVIOUS WORK

Chert Gravels:

Literature concerning the origin of upland chert gravels in eastern Kansas can be traced back to the late 19th century. Mudge (in Parker 1884) stated that the upland gravels near Burlington were modified drift. Parker (1884) believed the gravel beds may have been either deposited by glacial action or the result of drift transported southward from the glacial limit of northeastern Kansas. West (1885) declared the water-worn upland gravel in eastern Kansas to be the product of the submergence of southeastern Kansas under a sea during the Carboniferous Period.

Haworth (1896) thought the gravel deposits were more or less formed in situ and were simply the result of more resistant chert remaining after more perishable limestone had dissolved away. Wooster (1914) also believed that the gravels were due to peneplain accumulation. He noted that the chert gravels and fossils found with gravels were similar to those of the Wreford Limestone found in the Flint Hills. Wooster proposed the upland gravels to the east of the Flint Hills had weathered from the Wreford Limestone when it covered eastern Kansas. The more resistant chert gravel remained in place as the westward dipping outcrops of Wreford Limestone receded westward due to erosion.

The linear pattern of high-level chert gravel deposits suggested an alluvial origin to O'Connor (1953). He noted that the gravels closely parallel the modern Neosho and Verdigris rivers in their upper drainage systems and then diverge from them, continuing eastward instead of following their current trend. O'Connor also pointed out the fact that, as the high-level chert gravels are traced eastward from Lyon County, the gravels become higher and higher in the local topography until in Anderson County they occur at the highest topographic positions.

Frye (1955) noted that these upland chert gravels in Anderson County were more than 75 m (250 feet) above the valley floors and cap the divide between the Missouri and Arkansas drainage basins (Fig. 1). The position of the gravels on a major drainage divide led Frye to conclude also that the gravels may have been deposited by a stream which flowed eastward into Missouri rather than following the southeastward route of the Neosho River. Frye estimated the age of the topographically highest gravels to be late Tertiary due to their position relative to the modern river valley floor.

Aber (1985) also believed the deposits were alluvial in origin. The petrology and color of exotic quartzites in the upland gravels along the main stem of the Cottonwood and Neosho River valleys led Aber to propose a great preglacial river, named the Old Osage River, which deposited not only gravels derived from local cherty limestones but also exotic pebbles derived from the High Plains of central and western Kansas. This proposal was in contrast with theories of the previous thirty-three years, which stated that the Flint Hills formed a drainage divide during the Tertiary (Frye and Leonard 1952; Seevers and Jungman 1963; Bayne and Fent 1963).

Law (1986) found that pebble and cobble roundness values of upland chert gravel samples taken along the Neosho drainage system from Chase County eastward into Anderson County indicated a transport direction of gravels from west to east. Law also reconstructed the gradient along this main stem of the Old Osage by plotting elevation of the gravels and found the gradient to be similar to the modern gradient of the Neosho.

Structure and Drainage Development in Chase County:

The presence of anticlines and synclines in Chase County has been recognized for some time. Swallow (1866) reported:

> "The strata have been considerably disarranged by internal action that produced dips amounting to two hundred feet per mile (40 m/km). The most prominent are toward the northeast, and exhibit faults and fractures to a considerable extent. These dips form synclinal axes at Cottonwood Falls."

Haworth (1896), in describing strata along the Cottonwood River from east of Emporia westward to Cedar Grove (Cedar Point) in Chase County, reported a north-south trending synclinal trough located near Strong City (Fig. 13). He noted that although the Cottonwood Falls limestone (Cottonwood Limestone) passes downward out of sight north of Strong City it reappears approximately 3 km (two miles) farther west. Since the trough trends north-south, the limbs of the trough are also visible on the south side of the Cottonwood River valley. In tracing

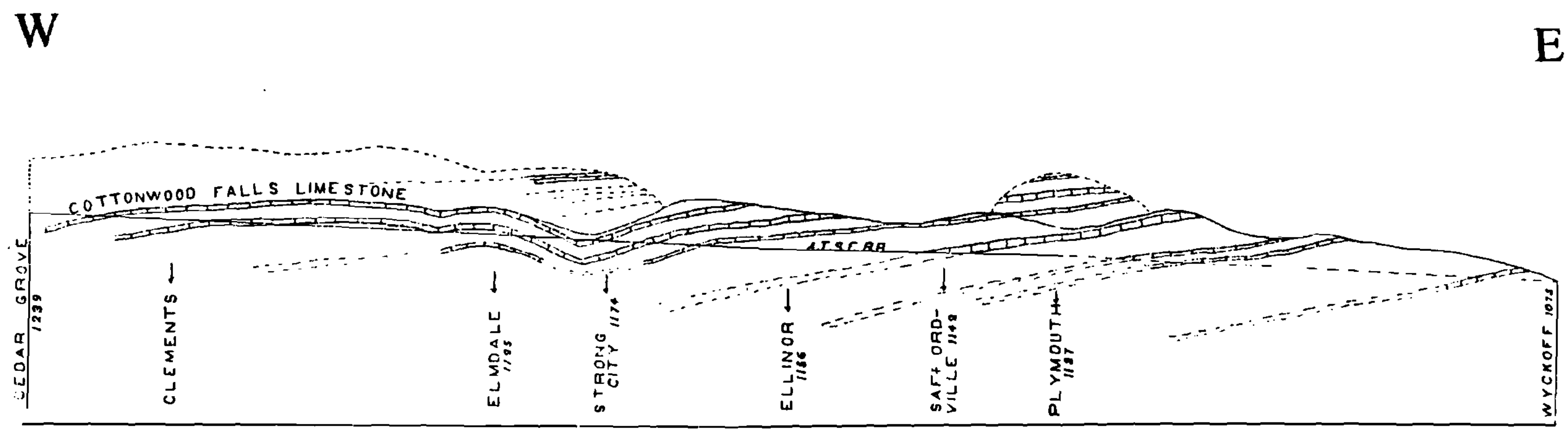

Figure 13. Section of sedimentary rock strata along the Cottonwood River from east of Emporia to southwestern Chase County. Approximate distance from Wycoff to Cedar Grove (Cedar Point) is 70 km (43 miles). Elevations listed are in feet above sea level. Note the trough at Strong City. Adapted from Kirk in Haworth (1896, plate 3).

the Cottonwood Limestone along the south side of the valley Haworth wrote:

> "As one passes westward along the wagon road from Cottonwood Falls the limestone is seen to pass under the first little hill west of the town and is seen no more throughout the distance of about two miles (3 km). Suddenly it is seen to rise out of the ground making an angle of three degrees with the horizontal. The first limestone beneath it also appears only a few rods further west, so that seemingly the two are entirely conformable with each other. From this place they continue to rise westward to the high hilltop just east of Elmdale Mills. As this hill is higher than the one on which the Cottonwood Falls quarry is located and is five miles (8 km) to the west one may readily see the importance of this great synclinal trough. Had the limestone continued to dip to the west at the angle common to most formations in this part of the state it would be at least 200 feet (60 m) below the hill at Elmdale Mills instead of being on its very summit."

Although Haworth did not speculate as to the cause of the observed deformation, Fath (1921) proposed that much of the folding seen in the midcontinent region of the United States was due to deep-seated adjustments along faults and other lines of weakness in the Proterozoic basement rocks of the area. He indicated that faulting in the deeper, more competent crystalline basement rocks would result in the folding of less competent sedimentary rocks at the surface. In addition, Fath stated that the parallelism seen in the fault belts of the midcontinent was likely due to nearly horizontal movements along line of weakness in basement rocks. Shorter fractures, which strike diagonal to the main fault lines, are due to the wrenching action caused by lateral movement along the faults.

A joint pattern study of upper Pennsylvanian and lower Permian limestones in Butler, Cowley, and portions of Chase and Greenwood Counties by Ward (1968) indicated that there are two major orientations of joints in the area. Ward dated the two joint systems as post-early Permian but pre-Cretaceous. Joint Set I strikes between 50° and 70° and Set 2 strikes between 304° and 336°. Both sets were created by shearing forces. A third minor set of joints, whose orientations cluster around the orientation of the two major joint sets, as formed from tensional forces. Similar joint orientations occur throughout Kansas and Oklahoma, and may be indirectly related to the wrench-fault tectonics of the Ouachita Orogeny and/or to tectonic influences from the Rocky Mountain region.

There has also been interest in the influence of subsurface structure on physiography. Many stream valleys and topographic breaks in eastern Kansas seem to follow major faults or fault zones. For example, in Chase County, Berendsen and Blair (1986) noted that Cedar Creek parallels the south bounding fault of the Cedar Creek syncline. Another example cited in the county is the much rougher terrain west of the Humboldt fault in the vicinity of the Elmdale dome compared to east of the fault. Berendsen and Blair also associated surface faults with tectonic zones such as the en echelon faults north of Elmdale on the flank of the Elmdale dome.

White (1990) investigated the relationship of structure on stream development in a study area that included portions of Chase, Butler, and Greenwood Counties. He found that the orientations of lineaments, which included stream valleys, were similar to the orientation of the joint system of the study area. He found the following lineament/joint orientation relationships: $30^{0}/30^{0}$, $300^{0}/295^{0}$, $320^{0}/320^{0}$, and $330^{0}/295^{0}$. The $30^{0}/30^{0}$ (north-northeast trend) relationship corresponds to the larger Humboldt fault zone, which crosses the state at approximately the same orientation.

Aber (1992) also reported the influence of structural features on drainage development to the south of Chase County in the Walnut drainage basin of Butler County. He noted that streams in the county follow synclinal troughs in places. He also found that most eastern tributaries of the Walnut River are parallel to a 50-65^{0} joint set (Fig. 14). Western tributaries follow valleys which correspond to a 310-335^{0} joint set, which corresponds to major lineaments of eastern Kansas.

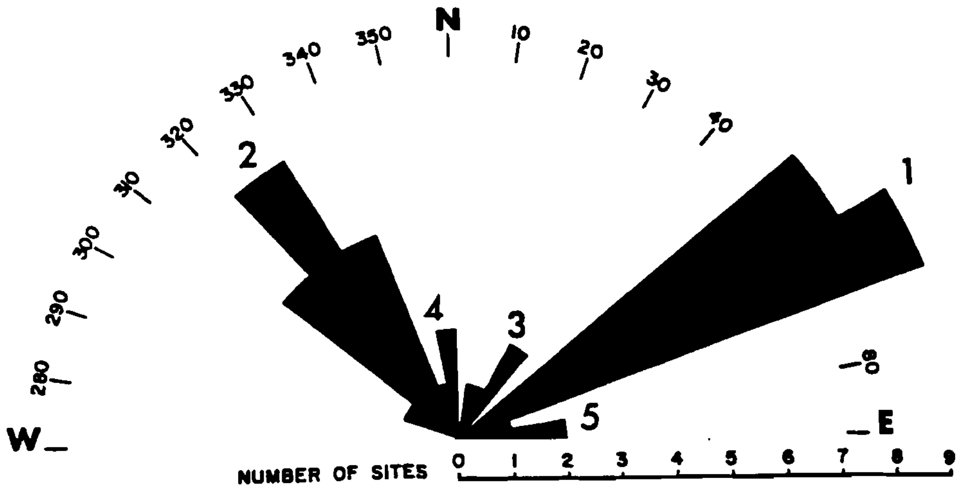

Figure 14. Joint strike orientations for Butler County. Scale indicates number of sites with joints in each 10^0 interval, and numbers indicate joint sets. Taken from Aber (1992, figure 7).

* * * * * *

CHAPTER 3. METHODOLOGY

Introduction:

The study consisted of two major themes: 1. the study of drainage development and upland chert gravels in Chase County; 2. the addition of Olpe Soil/chert gravel sites in Chase, Neosho, and Wilson Counties to the the existing KS-CHERT database of eastern Kansas. The study involved the creation of several maps:

1. Map showing the approximate areal coverage of upland gravels in Chase County.
2. Lineament map of stream valleys in Chase County.
3. Map comparing surface drainage to subsurface fractures in Chase County.
4. Digital elevation map showing elevations of the Cottonwood Limestone in Chase County.
5. Updated map of chert gravel elevations for the KS-CHERT database.

All maps were constructed through the use of the IDRISI geographic information system (GIS). IDRISI is both a geographic information and image processing system developed by J. Ronald Eastman of the Graduate School of Geography at Clark University, Worcester, Massachusetts. Designed as a low-cost, high-quality, raster-based, microcomputer GIS, IDRISI is used in over 80 countries and is the largest system of its kind on the market (Eastman 1992). A wide range of users include governmental agencies, educational institutions, urban planners and resource managers.

TOSCA, which is the the digitizing package sold with IDRISI, was also used in the creation of the maps and images. Developed by Jeffrey Jones of Clark University, TOSCA is a significant improvement over older digitizing programs. With TOSCA, vectors (lines, points, polygons) can be created, edited, and connected from an interactive on-screen display. Vector files can then be copied to IDRISI for further processing.

Computer hardware used in the project included a Microtech 486/33 Mhz PC-style computer. The computer has a 650 mb hard drive with 16 megabytes of memory. The monitor used was a 16-inch Nanao Flexscan super VGA monitor. A Hitachi digitizing table was used for digitizing vectors. The digitizing manual indicates a minimum resolution of 0.001 inch and an accuracy of 0.005 inch at 22° C.

The base map used for digitizing Chase County streams and recording upland gravel elevation and areal coverage data was the *Chase County, Kansas 100 000-scale Metric Topograhic Map* (United States Geological Survey 1991). The county map shows contours and elevations in meters, highways, roads and other manmade structures, water features and geographic names. Similar county topographic maps were used for recording Olpe Soil/chert gravel elevation data in Wilson (United States Geological Survey 1987) and Neosho (United States Geological Survey 1982) Counties. All three maps have a Universal Transverse Mercator projection and a 10,000-meter grid. Chase County is in UTM zone 14, and Wilson and Neosho Counties are in UTM zone 15.

IDRISI mapping of the upland gravel deposits involved the transfer of information from traditional paper maps to the computer database. The first step was to highlight all Olpe Soil (Figs. 15 and 16), which has been demonstrated to contain the upland gravels (Law 1986; and Aber 1992), in the soil surveys of Chase, Wilson and Neosho Counties. In Chase County, Olpe Soil is known as the *Olpe-Smolan complex* (Neill 1974), in Wilson County as the *Kenoma-Olpe silt loam* (Swanson 1989), and in Neosho County as the *Olpe-Dennis complex* (Fleming et al. 1982). A typical description of Olpe Soil is adapted from *Soil Survey of Chase County, Kansas* (Neill 1974):

A1: 0 to 23 cm, dark grayish-brown (10 YR 4/2) gravelly silt loam, very dark brown (10 YR 2/2) when moist; strong, medium, granular structure; slightly hard when dry, friable when moist; weak, thin platy structure in upper 2.5 cm; upper 8 cm is largely free of gravel; the lower 15 cm is 30 percent rounded chert pebbles 1 cm to 6 cm across; many roots; medium acid; gradual, wavy boundary.

B1: 23 to 46 cm, reddish-brown (5 YR 4/3) gravelly heavy clay loam, dark reddish brown (5 YR 3/3) when moist; strong, fine and very fine, subangular blocky structure; hard when dry, firm when moist; patchy clay films; horizon is 50 to 60 percent rounded chert pebbles 0.6 cm to 8 cm across; many roots; slightly acid; gradual wavy boundary.

B2t: 46-152 cm, reddish-brown (2.5 YR 4/4) gravelly silty clay, dark reddish brown (2.5 YR 3/4) when moist; strong, fine and very fine, angular blocky structure; extremely hard when dry, very firm when moist; continuous,

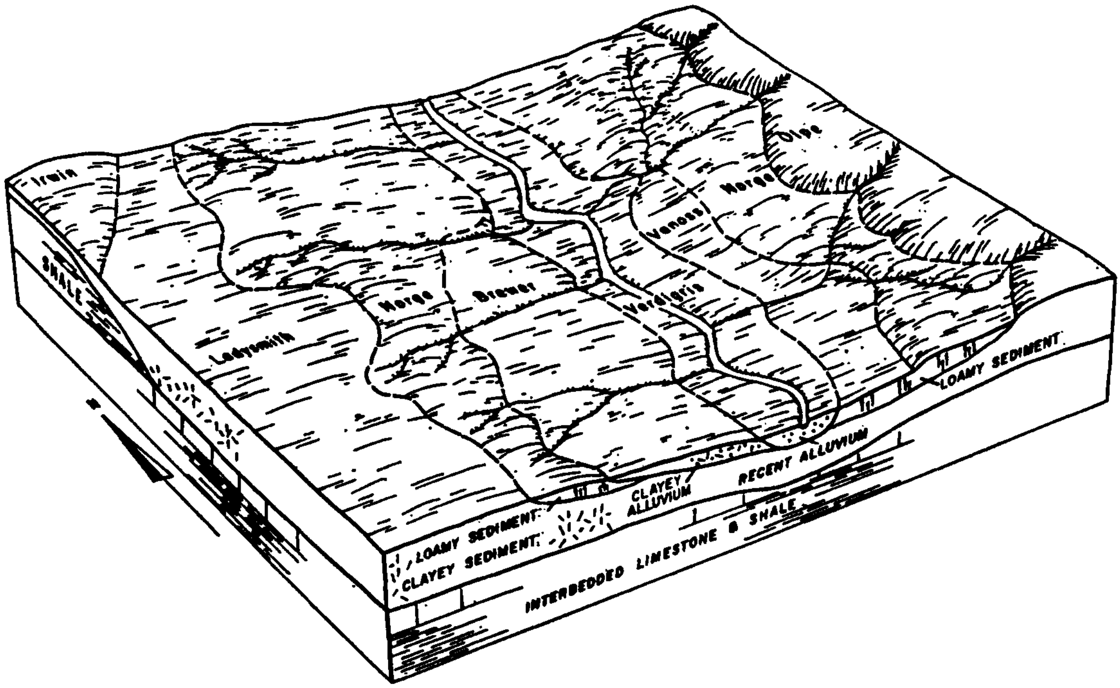

Figure 15. Diagram showing the high-terrace position of Olpe Soil in the topography. Adapted from Penner et al. (1975, p. 6.)

Figure 16. Photographs of Olpe Soil taken at Bazaar Cemetery west of Bazaar, Chase County: NE1/4 Sec. 32, T20S, R8E.

blocky structure; extremely hard when dry, very firm when moist; continuous, thick clay films; horizon is 80 to 85 percent rounded chert pebbles 0.6 to 6 cm across; few roots; neutral.

Areal Coverage Map of Upland Chert Gravels in Chase County:

A map showing the location and approximate areal coverage of chert gravel deposits was created using TOSCA. Features on the map include streams of the county as well as the location and approximate areal coverage of gravel per quarter section of land. Transportation features and town locations distracted from the primary focus on upland gravel deposits, so they were not included on the map.

Drainage in the county was digitized first. Streams were digitized from the 1:100,000-scale contour map of Chase County. Streams shaded a heavier blue or named were included on the gravel map. Although it was a time consuming process, the digitization of the streams was worthwhile because the streams could be used in the production of various other maps.

The areal coverage of the gravels by quarter section was divided into four categories: 1. 10-19 acres 2. 20-39 acres 3. 40-79 acres 4. 80-160 acres. The coverage was estimated by creation of a 10, 20, 40, 80 and 160-acre template, which was scaled to match the sections of the *Soil Survey of Chase County, Kansas* (Neill 1974). The clear template was overlaid on the sections containing Olpe Soil. Additional data on the locations and areal coverage of gravel deposits were obtained in a similar manner from the *Areal Geology of Chase County, Kansas* (Moore et al. 1951). In cases where quarter sections were covered by both the soil survey and geologic map, the map with the larger coverage of gravel was used. It should also be noted that areal coverage does not indicate the thickness of the gravels, which may range from a thin covering of less than one meter to deposits a few meters thick.

Once the locations and areal coverages of gravel deposits were identified, the information was recorded in a quarter-section grid on the 1:100,000 base map and then digitized. Points were digitized as close to the center of the quarter section as possible. Because IDRISI cannot import files which contain both point (gravel) and line (stream) data, two separate files were saved and placed into a script file. A script file is a set of instructions which tells IDRISI how to plot files, and allows files to be overlaid.

Lineament Map of Stream Valleys in Chase County:

The very straight valleys of many of the streams of Chase County suggest bedrock structural controls which may be influencing drainage development in the county. A lineament map of the county was created using IDRISI and the accompanying TOSCA digitizing program. The lineaments of the straightest of the valleys were drawn onto the 1:100,000-scale Chase County topographic map and then digitized. Each lineament was given a unique feature identifier so that editing of individual features could be accomplished without editing the entire map. The data were then transferred to IDRISI for further processing. A rose diagram showing the orientation of valley lineaments was also constructed.

Map of Subsurface Fractures vs. Drainage Patterns, Chase County:

Drainage patterns in Chase County appear to have a relationship to the orientation of subsurface fractures. Proterozoic basement rock units in Chase County are relatively shallow (less than 600 m) in places and may indirectly influence the fracturing of overlying Paleozoic rocks (Berendsen and Blair 1986). A map showing possible relationships was developed by using the Chase County stream file already produced for other maps and overlaying it with subsurface fractures taken from a structural contour map on top of the Arbuckle Group (Berendsen and Blair 1986). The Arbuckle Group consists of carbonate rocks and ranges in age from the Cambrian Period to the Ordovician Period.

The locations of fractures were transferred from the structural contour map to the 1:100,000-scale base map and digitized. An attempt was made to digitize fractures directly from the structural contour map and then overlay the images, but the different map projections made it difficult to obtain an accurate match. A rose diagram was also made for the orientations of fractures on top of the Arbuckle Group.

Digital Elevation Model of Cottonwood Limestone Elevations:

A digital elevation model was developed with IDRISI by using elevation data of the Cottonwood Limestone exposed at the surface in Chase County. A digital elevation model interpolates between elevation points and creates an image of the topography of an area when viewed in three dimensions with the ORTHO module of

IDRISI. Plotting elevation points of the Cottonwood Limestone allows determination of whether structural controls are influencing drainage development.

The Cottonwood Limestone member of the Beattie Limestone (Fig. 8) can be traced from south-central Nebraska to northern Oklahoma. The Cottonwood Limestone was selected because of its fairly consistent thickness of 1.5-1.8 m (5-6 feet) throughout the county and because it forms distinctive stone lines in many hills in Chase County (Fig. 17). The color of the limestone ranges from a massive gray to creamy buff and weathers to a light gray. The upper half of the limestone contains abundant fusulinids while the lower half is more platy and contains echinoderm fragments, bryozoans, brachiopods, and algal material which give it a crushed "potato chip" appearance when viewed in cross-section (Moore et al. 1951; Twiss 1988).

The distribution of exposures of Cottonwood Limestone limited the study area to townships 18, 19, and 20 south. Data were gathered in various ways. Due to the fact that many Cottonwood Limestone exposures are relatively inaccessible by car, much of the data were obtained through the combined use of aerial photographs in the *Soil Survey of Chase County, Kansas* (Neill 1974), *The Aerial Geologic Map of Chase County* (Moore, Jewett, and O'Connor 1951), and 1:24,000 topographic maps published by the United States Geological Survey. The aerial geology map was consulted first for locations of Cottonwood Limestone. If an outcrop of the limestone was visible in the soil survey photographs, then the elevation was checked on the topographic map. Some of the topographic maps have a 6 m (20-foot)

Figure 17. Photographs showing outcrop of Cottonwood Limestone east of Cottonwood Falls, Chase County: SW1/4 Sec. 29, T19S, R9E.

contour interval while others use a 3 m (10-foot) contour interval, so overall, the elevations should be within ten feet and in some places as close as five feet of their true elevation.

One hundred and thirty-four Cottonwood Limestone elevation points were used, thirty of which were control points. Control points are places where the elevations of limestone were measured with the use of a surveying altimeter. Twenty-four control points were obtained from previous work conducted by a fellow graduate student with the remaining 6 points added from exposures along the South Fork of the Cottonwood River. An American Pauline System altimeter was used to determine the elevation of the control points. A surveying altimeter is essentially a barometer which measures changes in elevation by the subtle changes in barometric pressure which accompany changes in elevation. It is much faster than plane table mapping in determining elevations.

The altimeter must be taken to a place with a known elevation such as a benchmark and calibrated to the site before gathering elevation data. Temperature readings are also taken and used to correct elevation readings. Time is also recorded. Elevation readings for the Cottonwood Limestone were taken at various locations and the time noted. Readings at known elevations must be taken along the way for comparison so that corrections can be made for temperature and barometric changes. Limitations or ways that error can arise include not allowing the thermometer to swing freely, exposing the thermometer and the altimeter to direct sunlight, not properly leveling the instrument, as well as rapid changes in barometric pressure.

All elevation readings were transferred to the 1:100,000 base map for digitizing with TOSCA. The file was saved as a point coverage file (raw data file name is COTLSEL, see appendix for viewing instructions) and the actual identifiers were saved as real numbers so they could be used directly for the digital elevation modeling. The INTERPOLATION module of IDRISI was used to create a raster-based digital elevation model. The interpolation module can use the identifiers as heights in creating the model rather than assigning attribute values to each point. The module interpolated the points by using between 4 and 8 (usually 6) of the closest data points to any given grid cell. A reclassified version with a legend was created to overlay on the original version for three dimensional display using the ORTHO module of IDRISI.

Updating Elevation Data for the KS-CHERT Database:

The KS-CHERT database, which contains the elevations of upland chert gravels in a portion of east-central Kansas (Fig. 3), records the elevation data in a raster fashion, meaning each cell is given a unique column and row number. Raster storage of data made it easy to create a workable database without the time consuming approach of digitizing each gravel deposit. Each cell in the database represents approximately one quarter section of land. A township range system was selected for use despite the limitations of odd-sized and offset sections, because it is easy to use and elevation of the gravel is the primary focus of the study.

Quarter sections containing at least 10 acres of Olpe Soil/upland chert gravel were recorded from both the soil survey and the *The Aerial Geology of Chase*

County (Moore et al. 1951) on 1:100,000-scale metric county topographic maps. The highest elevation containing Olpe Soil in a quarter section of land was recorded on the topographic maps. The Chase County topographic map was divided into a 52 column by 64 row grid. Three rows of gravel data from southern Morris County were also included in the Chase County grid (raw data file name is CHRTELV, see appendix for viewing instructions).

Soil surveys were also consulted for identifying Olpe Soil in Wilson and Neosho Counties. Quarter sections containing at least 10 acres of Olpe Soil were recorded on 1:100,000-scale topographic maps for these counties. Both Neosho and Wilson County maps were divided into 48 column by 48 row grids.
Actual column and row numbers were assigned in Wilson and Neosho Counties so they would match with the numbering system of the 180-row by 226-column KS-CHERT database.

The INITIAL module of IDRISI was used to make corresponding blank grids for each county before the locations and elevations of Olpe Soil were transferred to the raster-structured database. Each cell of the grids represents 0.8 by 0.8 km (0.5 by 0.5 miles), which corresponds approximately to the quarter sections on the topographic maps. The UPDATE module was then used to enter elevations into the proper grid location.

The Wilson and Neosho County data were combined into a single file and added to the KS-CHERT database using the OVERLAY module of IDRISI. The Chase-Morris County grid was added to the KS-CHERT with the CONCAT module because it allows the joining of two grids whose numbering systems do not match (raw data file name CHERT, see appendix for viewing instructions). A visually appealing image was created by using the RECLASS module to more evenly classify the elevations into 15-meter intervals. A special color palette was developed to use with the image to create a better visual transition from lower elevations (cool colors) to higher elevations (warm colors).

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CHAPTER 4. RESULTS AND INTERPRETATION

Upland Chert Gravels of Chase County:

The map displaying the coverage of upland chert gravels is shown in Figure 18. The areal distribution of gravels is the greatest along the Cottonwood River and South Fork. The gravels are preserved nearly the whole length of both valleys. Many other smaller tributaries such as Fox Creek, Bloody Creek, Middle Creek, and Cedar Creek also contain the upland gravel deposits. In addition, gravels are preserved along North Branch Verdigris River. Gravels are also found along Kahola Creek on either side of the Chase-Morris County boundary.

There is a noticeable lack of preservation of upland gravels along Diamond Creek, where the only deposits are near its junction with Middle Creek and the Cottonwood River. Perhaps the older gravel deposits were removed by erosion, or headward erosion of Diamond Creek occurred after deposition of the upland gravels. A similar scenario can be found in Lyon County in the Neosho River valley north of Emporia. Like Diamond Creek valley, the Neosho River valley is a conspicuous lineament with a northwest orientation that lacks upland gravels in its upper reaches (Aber and Johnston 1990).

Another noticeable lack of gravels occurs along the northern side of the Cottonwood River Valley near Strong City. This site coincides with the location of a structural basin centered near Strong City and with an area where the Cottonwood River abruptly changes course from the southern side of the valley toward the northern side of the valley. If this basin is gradually subsiding, then the change of

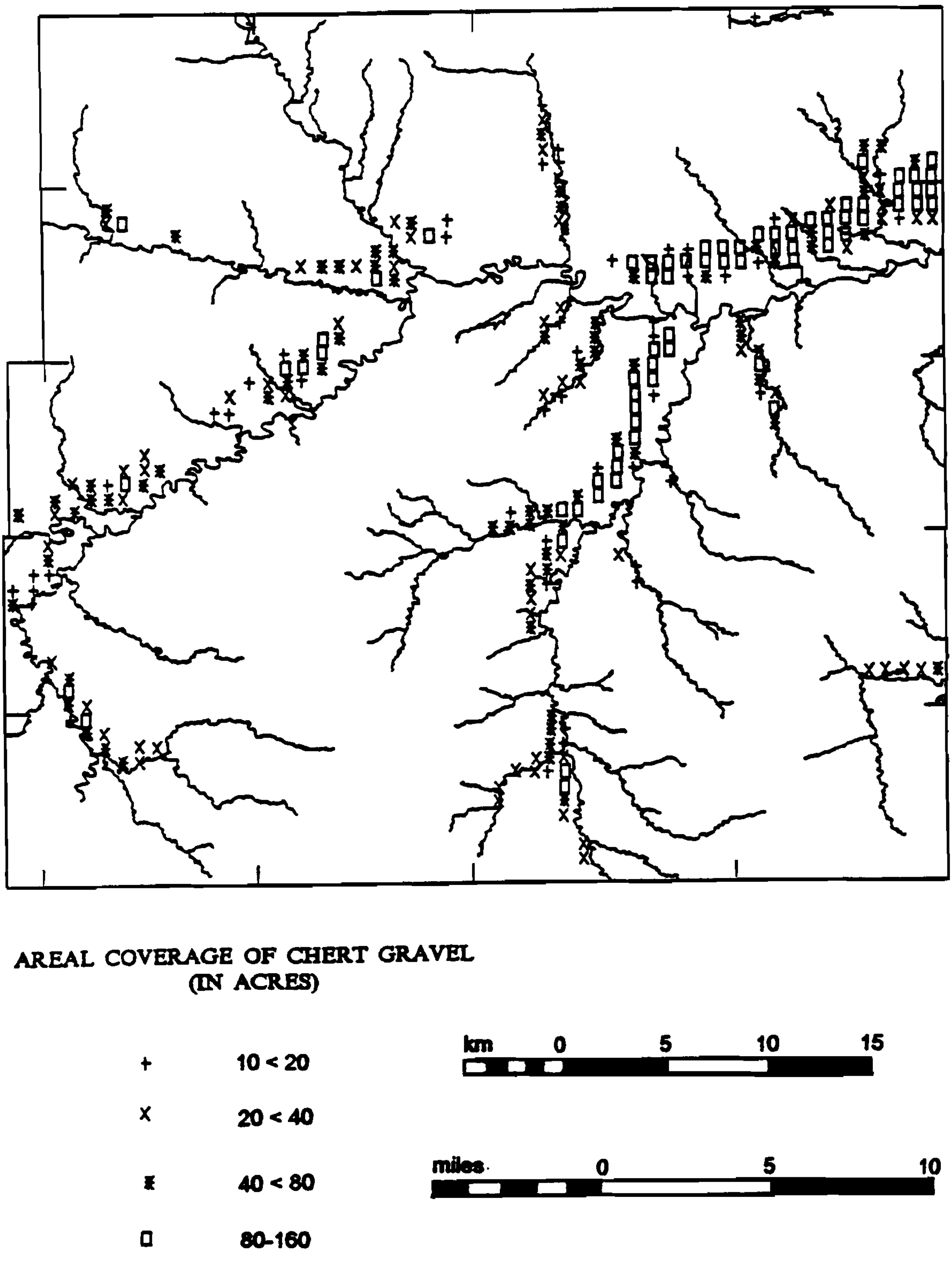

Figure 18. Map of Chase County showing distribution of chert gravel (Olpe Soil) and streams. Legend indicates areal coverage of gravel per quarter section of land.

course of the Cottonwood River toward the basin should be a predictable result. A gradually subsiding basin would create just enough change in gradient to divert the route of the Cottonwood from its typical route along the southern side of the valley toward the subsiding basin on the northern side. Therefore, the lack of upland gravels near this basin may be due to erosion by the Cottonwood River at this location.

The Olpe Soil/chert gravel elevation data for Chase County (file name CS-CHERT, see appendix for viewing instructions) indicate elevations ranging from 350 meters on the low terrace of the Cottonwood River east of Strong City to an elevation of over 420 meters along the South Fork near Matfield Green. Sleezer (1990), in his upland gravel study of Butler County, divided gravel deposits into two categories according to their elevation relative to the modern floodplain. Hill-top gravels, which are located on or near the top of hills, are more than 20 meters above the modern floodplain. High-terrace gravel deposits are those deposits which are less than 20 meters but greater than 10 meters above the modern floodplain.

Hill-top gravels along the Cottonwood River range in elevation from 400 meters near the Marion County border to 370 meters at the Lyon County border. High-terrace deposits are especially widespread along the South Fork where their elevations range from 420 meters to 370 meters. The high-terrace deposits of the Cottonwood River east of Strong City form a distinct band at elevations ranging between 370 meters and 350 meters at the Lyon County border. These high-terrace deposits along the South Fork and the eastern portion of the Cottonwood River are associated with the Emporia Terrace.

The gravel deposits are located primarily on the west side of streams that flow in a northerly direction; whereas for easterly flowing streams, they are preserved on the north side of the stream valley. This asymmetrical preservation of gravels has been noted by earlier workers (Law 1986; Sleezer 1990; Aber 1992) in other counties in eastern Kansas. Explanations for the asymmetrical preservation of gravels in eastern Kansas include the Coriolis effect, unequal sediment input into stream valleys and neotectonic uplift or tilting in the region. The Coriolis effect does not seem to be a major influence in drainage development (Aber 1992).

Unequal sediment input into stream valleys does not appear to account for the asymmetrical gravel preservation in the county. Most major tributaries have entrenched into either the Florence or Wreford Limestones, so the source for chert gravel is uniform. A neotectonic structural arch with an axis paralleling the Kansas-Nebraska border has also been suggested as an influence on drainage development in the region, but direct evidence for the existence of this arch is lacking.

A recent proposal by Aber (1992) suggests the asymmetrical preservation of gravels may be due to slow, regional crustal downwarping to the south toward the East Texas Embayment of the Gulf Coast. The lack of gravels along the upper reaches of Diamond Creek may support the regional crustal downwarping toward the south. Diamond Creek flows in a southeasterly direction. If it is flowing parallel to the direction of regional crustal tilting, the stream should not migrate and asymmetrical preservation of gravels would not occur. However, there should be upland gravels preserved on either or both sides of Diamond Creek, but this is not the case. Although this lack of gravels may support the subtle crustal tilting toward the south, there may be other unknown influences which have inhibited preservation of gravels in the upper reaches of Diamond Creek.

Sleezer (1990) determined the amount of stream downcutting relative to lateral channel migration to measure the effects of crustal tilting on streams in Butler County. To judge possible effects of crustal downwarping along the Gulf Coast on streams in Chase County, the magnitude of stream downcutting in relation to lateral migration was investigated. In the valley of the Cottonwood River southwest of Elmdale, the river has downcut as much as 30 meters and has migrated southeasterly as much as 2.6 kilometers since the deposition of hill-top gravel, for a vertical to lateral migration of 11.5 m/km.

At the Lyon County border, the Cottonwood River has downcut as much as 30 meters and migrated approximately 5 kilometers to the south for a vertical to lateral migration ratio of 6 m/km. On Middle Creek, the stream has cut down approximately 20 meters and migrated as much as 1.4 kilometers to the south since the highest gravel was deposited, which indicates a migration ratio of approximately 14 m/km. Toward the north end of the South Fork, there has been roughly 20 meters downcutting and a migration of the stream toward the southeast of as much as 2.4 kilometers for a migration ratio of about 8.3 m/km. Fox Creek has cut down approximately 10 meters and migrated roughly 0.5 kilometers for a migration ratio of 20 m/km.

A comparison was also made between the modern stream gradients and the older gradients represented by the highest elevations of upland gravels to determine

River	Old Gradient	Modern Gradient	Change
Cottonwood River	0.72 m/km	0.72 m/km	none
South Fork	1.65 m/km	1.95 m/km	+0.30
Cedar Creek	1.91 m/km	2.16 m/km	+0.25
Middle Creek	1.78 m/km	2.45 m/km	+0.67
Fox Creek	3.08 m/km	4.10 m/km	+1.02

Table 1. Comparison of modern stream gradients and older stream gradients as represented by the present elevation of the topographically highest and therefore oldest chert gravels preserved in the valleys.

any significant changes in stream gradients which may have occurred due to crustal tilting. Approximate gradients were calculated for the Cottonwood River and its major tributaries. These streams contain mostly continuous bands of upland gravels along their valleys and are represented in Table 1.

Fox Creek appears to have the greatest change between the old and modern gradients. The fact that Fox Creek drains toward the center of a basin may explain the change in gradients. The basin may be slowly subsiding, causing an increase in gradient. The reason for change between the old and modern gradients of Middle Creek is more unclear, but it may be due to its drainage to the east toward the basin near Strong City. The overall slight increase between old and modern gradients could reflect subtle southward crustal tilting or possibly local crustal adjustments due to tectonic activity. Microearthquakes have been recorded in the area (Burchett et al. 1983), so local neotectonism is a possibility.

Structural Influences on Drainage Patterns in Chase County:

The investigation of the relationship between structural elements of the county and drainage development revealed a positive correlation. A comparison was made between the lineament map of Chase County stream valleys (Fig. 19) and the orientation of subsurface faults of the Arbuckle Group. A visual inspection of the map comparing the orientation of subsurface fractures to the orientation of streams (Fig. 20) reveals some relationships between the trends of stream valleys and subsurface fractures. For example, the Cottonwood River valley southwest of Elmdale and the South Fork valley north of Bazaar parallel north-northeast trending fractures in the Arbuckle. Several smaller valley tributaries such as Buck Creek and Spring Creek south of Cottonwood Falls also parallel the north-northeast orientation. Other stream valleys parallel the northwesterly orientation of some Arbuckle Group fractures. Middle Creek approximately parallels the northwesterly orientation as do the valleys of Coon Creek and Cedar Creek.

Further confirmation of the relationship was made by construction of rose diagrams. A rose diagram was created for the stream valley lineaments (Fig. 21) and for the orientation of subsurface fractures of the Arbuckle Group (Fig. 22). Data for the rose diagrams were grouped in 10° intervals as follows: 355° to 4°, 5° to 14°, etc. The rose diagram for stream valleys depicts the number of kilometers of stream valley with a specific orientation. The six preferred valley orientations are listed in descending order of abundance: 330°, 350°, 30°, 50°, 70°, and 290°, with other orientations scattered between these positions. The Arbuckle Group fault orientation data show a strong preference in the 30-40° and 310-320° orientations.

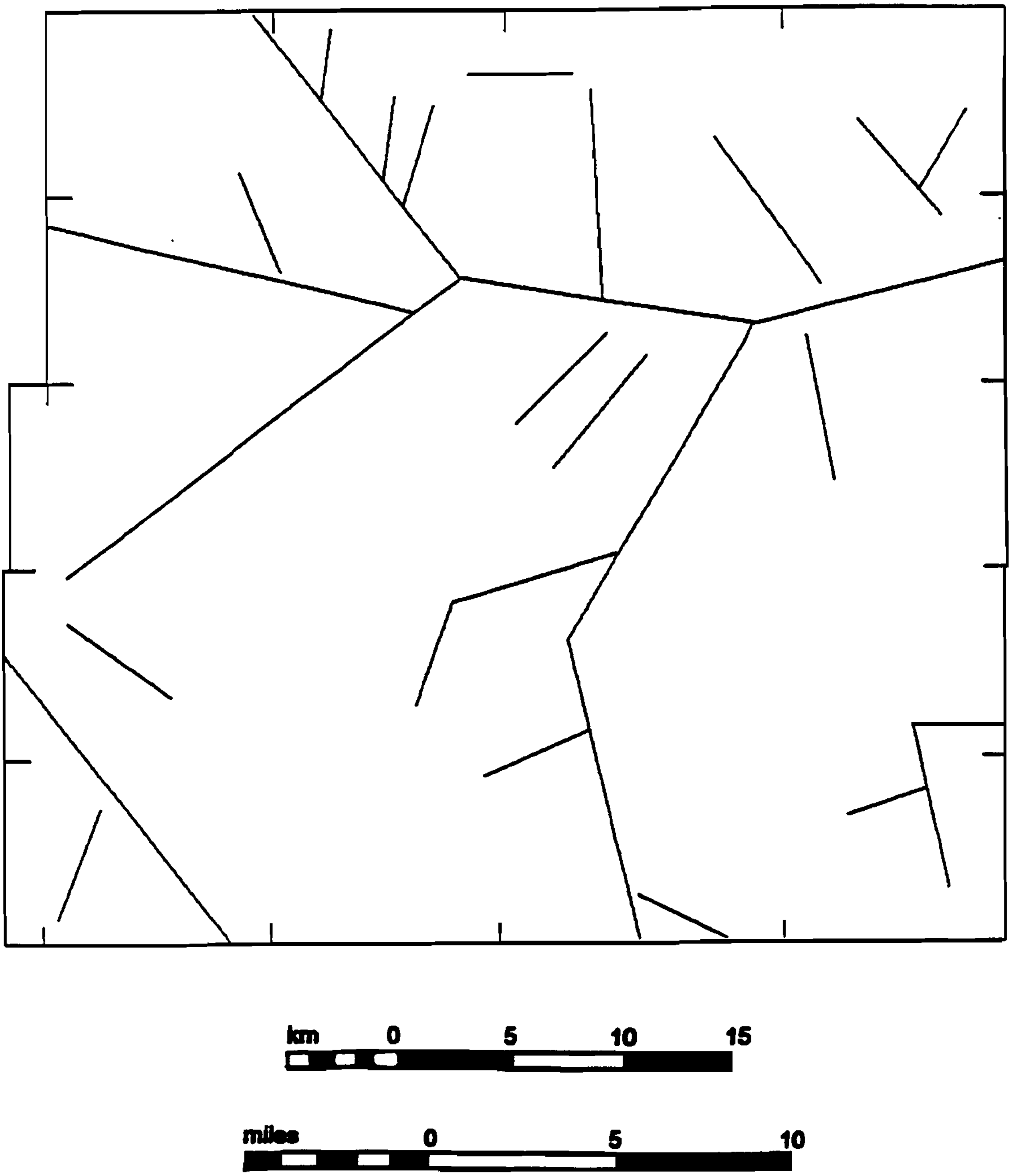

Figure 19. Map of stream valley lineaments in Chase County. Lineaments were digitized from a 1:100,000-scale topographic map of Chase County published by the United States Geological Survey.

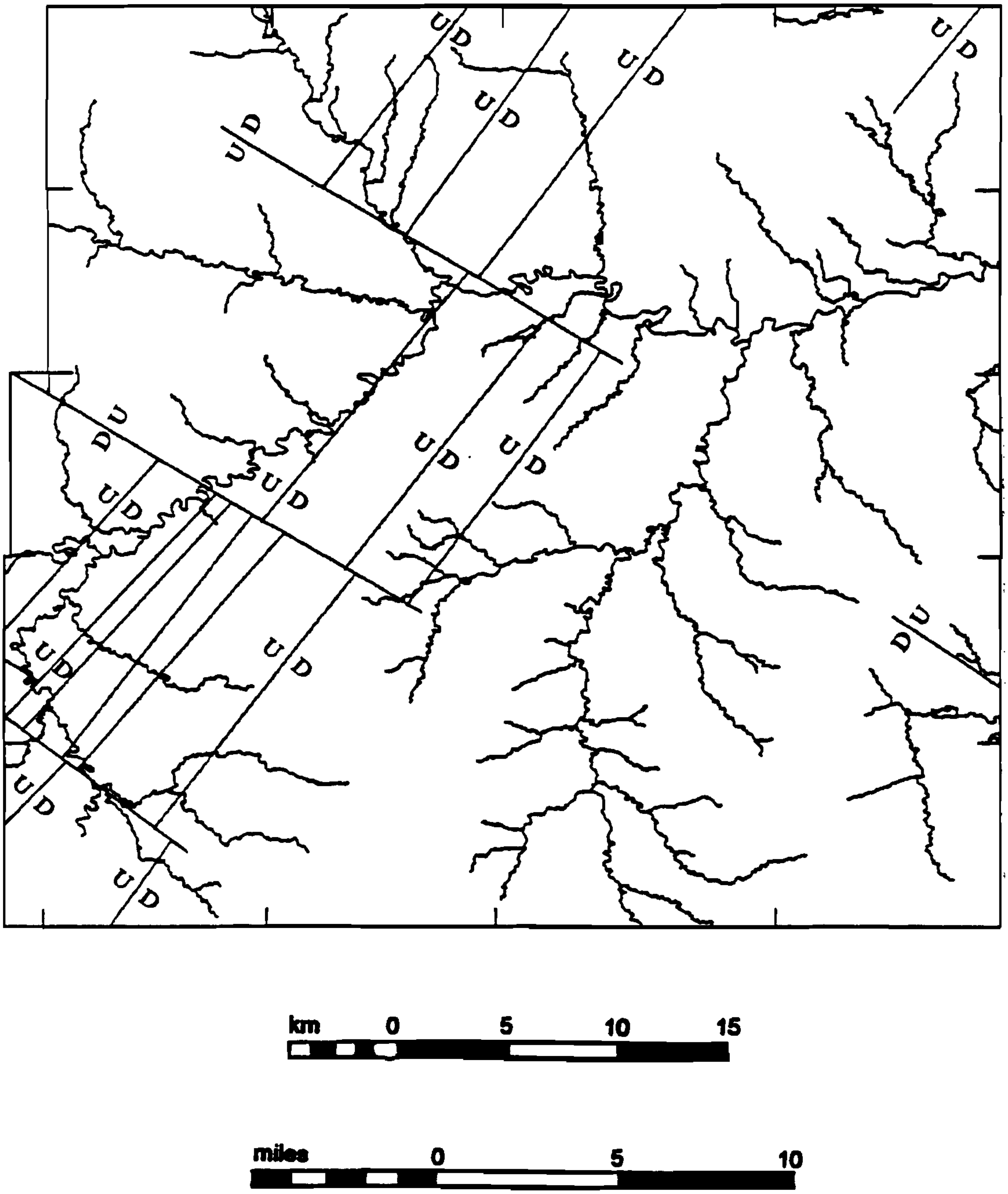

Figure 20. Map of Chase County showing the relationship between the orientations of subsurface fractures in the Arbuckle Group to the orientations of streams. U = upthrown side, D = downthrown side. Fractures in the Ordovician Arbuckle Group are a reflection of even deeper Proterozoic basement fractures. Approximate location and extent of Arbuckle Group fractures taken from Berendsen and Blair (1986, map 6).

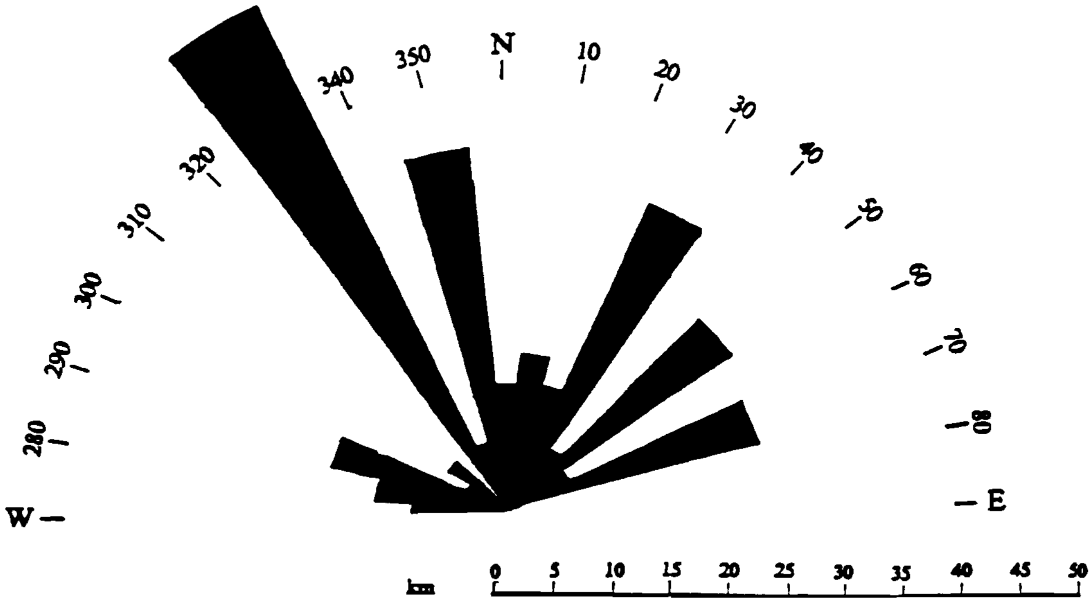

Figure 21. Rose diagram showing the orientations of stream valley lineaments in Chase County. Valley lineaments are classified in 10° intervals. For example, a 70° orientation includes all lineaments between 65° and 74°. Scale indicates the number of kilometers having a specific orientation.

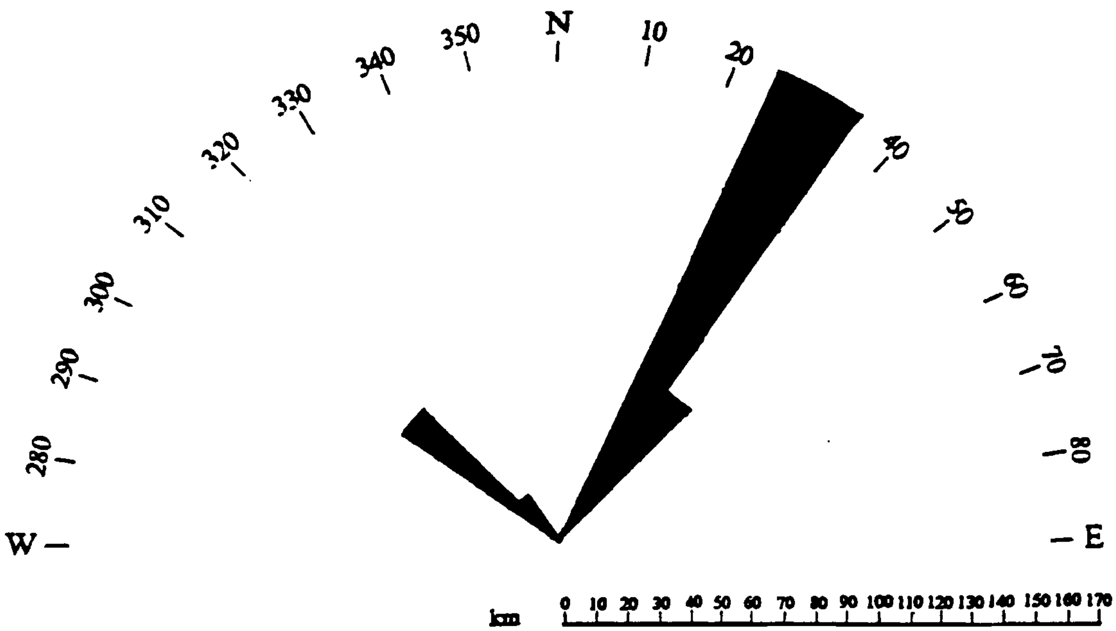

Figure 22. Rose diagram indicating the orientations of subsurface fractures in the Arbuckle Group of Chase County. Fracture data taken from Berendsen and Blair (1986). Scale indicates the number of kilometers of fractures having a certain orientation.

The 30^0 orientation of stream valleys seems to correspond with the primary orientation of Arbuckle Group fractures.

The stream valley orientations also correlate with surficial bedrock joint patterns in the region. Joint orientation studies conducted on limestones to the south in Butler County (White 1990; Aber 1992) indicate five major joint sets listed in descending order of frequency: 50-65°, 310-335°, 15-35°, 340-350° and 70-80°. The 50° and 70° valley orientations of Chase County may be related to the 50-65° and 70-80° joint orientations of Butler County. The similarities between joint and stream valley orientations and subsurface fractures seem to indicate that geomorphic and tectonic adjustments in the region have been along previously existing fractures or weaknesses.

The analysis of Cottonwood Limestone elevations indicates that deformation of strata also influences the drainage of the county. For example, the three-dimensional, orthographic projection of Cottonwood Limestone elevations (Fig. 23) reveals that the South Fork flows northward along the axis of a trough which plunges toward a basin centered near Strong City. This structural basin also seems to influence the route of the Cottonwood River near Strong City, where the river abruptly changes its course from the south side of the valley towards the basin on the north side of the valley. A more dramatic view of this trough and basin can be seen on the accompanying disk (file name COTLSELV, see appendix for viewing instructions). The viewer should keep in mind that the orthographic images are interpolated from point data of limestone elevations and are not necessarily representative of surface topography. There is also some exaggeration of features.

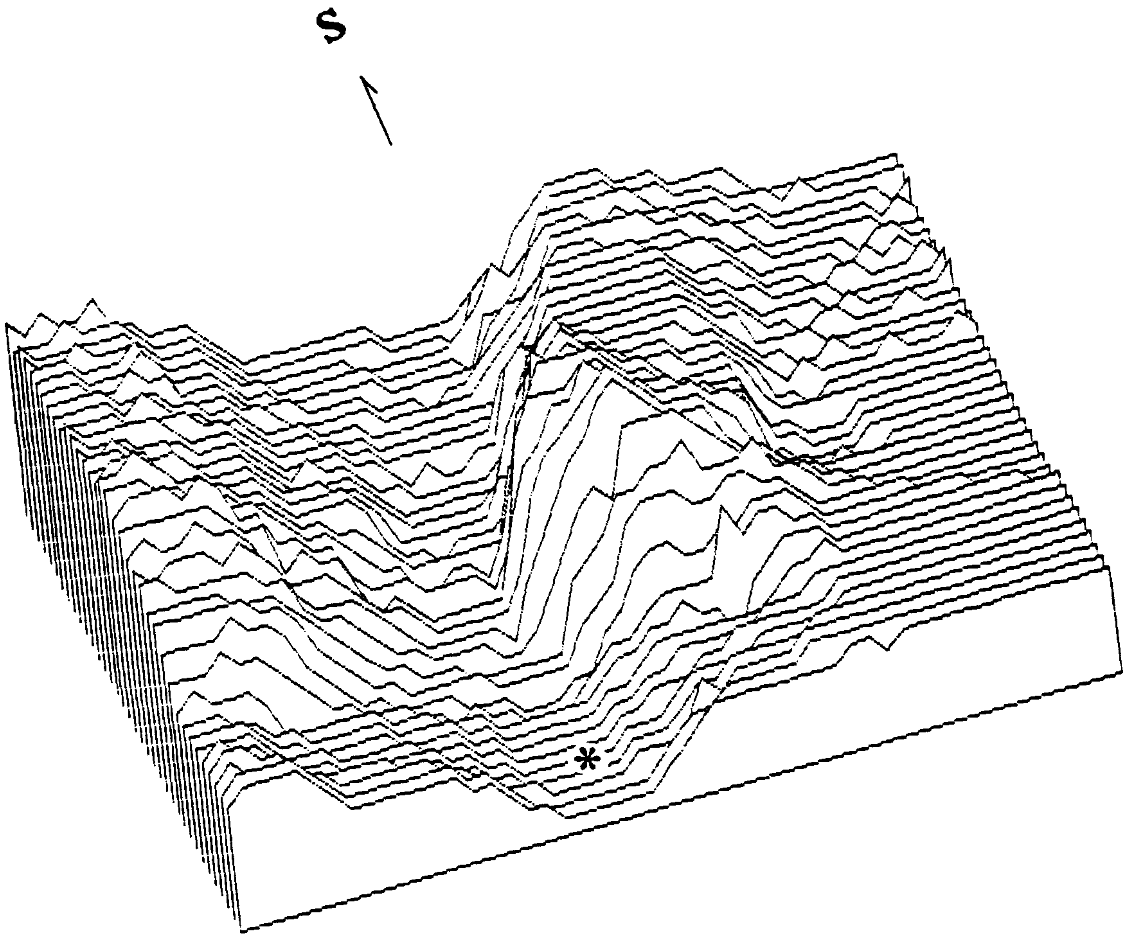

Figure 23. View of interpolated Cottonwood Limestone elevations in northern Chase County looking southward along basin and trough. Upper-right corner of the image is at a 195° orientation and the viewing angle is 45° above the horizon. South Fork of the Cottonwood River flows northward toward the basin centered near Strong City (asterisk indicates approximate center of basin). The highest portion of the anticline seen near the center of the image represents the highest elevation of Cottonwood Limestone and is located east of Elmdale. Diagram includes townships 18, 19 and 20 south.

The area covered by the basin appears on the subsurface fracture map (Fig. 20), as a downthrown area. The depression may be a pull-apart basin created where a northwest-trending fault transects a north-northeast trending fault. Lateral movement along north-northeast trending faults created tension at intersections with northwest-trending transverse faults, causing the downdropping of the pull-apart basin.

Analysis of Updated KS-CHERT Database:

The updated overall distribution of upland gravels in the study area is shown in Figure 24. A more informative KS-CHERT image showing both elevation and locational information can be viewed on computer disk (file name KS-CHERT, see appendix for viewing instructions). The updated KS-CHERT database calls for a somewhat different interpretation of paleodrainage patterns of the Neogene in eastern Kansas. The combination of existing locational information about quartzite-bearing gravels and the updated elevation data of the upland chert gravels led to the following three interpretations:

1. The main stem of the Old Osage flowed eastward across southern Lyon and Coffey Counties.
2. The main stem of the Old Osage exited the state through southeastern Kansas via the ancestral Neosho River into Oklahoma instead of eastward into Missouri.
3. The gravels of Anderson County were possibly deposited by a northern tributary joining the main stem of the Old Osage from the northeast.

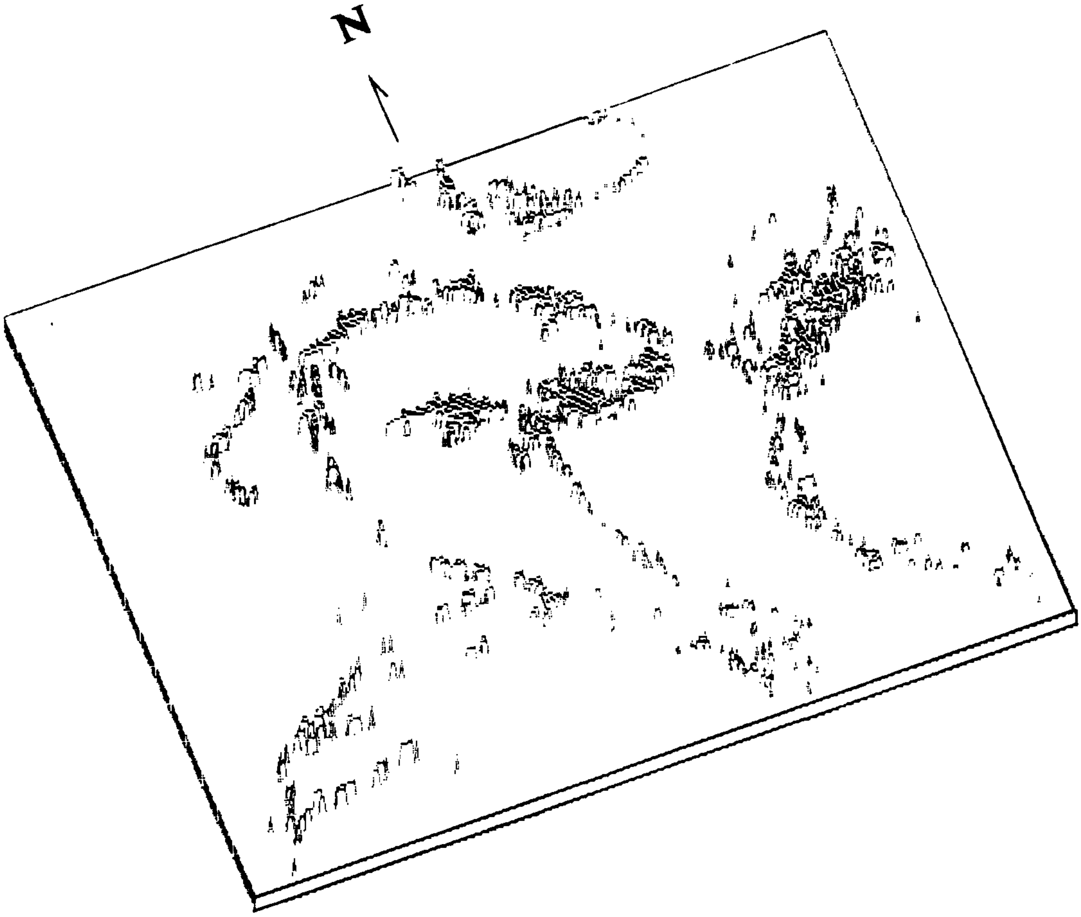

Figure 24. Distribution of Olpe Soil/chert gravel deposits in eastern Kansas. Refer to Figure 2 for county boundaries. Gravel elevations shown in relation to an arbitrary base elevation of 200 m. Image created using ORTHO module for viewing KS-CHERT. Upper right corner of figure is at a 20° orientation and the viewing angle is 65°.

The distribution and abundance of chert gravels suggests that the main stem of the Old Osage flowed across southern Chase and Lyon Counties, and through northern Greenwood County. In southern Coffey County, the Old Osage River joined with a tributary that flowed parallel to the present route of the Cottonwood and Neosho Rivers in Chase and Lyon Counties. The main stem of the Old Osage appears to have been dismembered by the headward erosion of South Fork.

The previous Olpe Soil database indicated that the course of the Old Osage River paralleled the Cottonwood and Neosho river valleys from Chase County eastward to Coffey and Anderson Counties , where the distribution of gravels seemed to imply that the Old Osage continued eastward. However, the addition of Olpe Soil elevations from Neosho and Wilson Counties shows that the Old Osage likely paralleled the course of the Neosho River southeastward toward the Oklahoma border. In addition, the elevations for gravels in Neosho and Wilson Counties are overall lower than the elevations of gravel in Coffey and Anderson Counties, which is another point in favor of the Old Osage flowing southeastward toward Oklahoma.

Aber (1985) and Law (1986) both noted that the Anderson County gravels are over 60 meters above the modern floodplain, topographically the highest and therefore oldest of the gravels. Assuming that the chert gravels follow a similar gradient to the modern stream gradient, Law (1986) projected an average stream gradient of 0.66 m/km (average gradient for the Neosho and Cottonwood Rivers) for Anderson County gravels westward into Chase County. He found that the elevation of the old stream would be well above the uppermost chert limestones of the area.

Law discounted the explanation that the ancient gradient was much less steep than at present because the size and roundness of the chert fragments did not suggest a lesser gradient. He assumed the gradients to be similar, and that the cherty limestones of the Flint Hills outcropped farther to the east. Law also assumed that all gravels in Chase, Lyon and Coffey Counties of equivalent age to the Anderson gravels had been eroded away.

An alternative to this explanation is that the Anderson County gravels were deposited from a stream flowing into the county from the northeast (Fig. 25). The stream, with headwaters in the quartzite-bearing Ogallala of the High Plains, may have flowed eastward across northern Kansas or southern Nebraska; it turned toward the south across northeastern Kansas or northwestern Missouri, and finally flowed to the southwest and joined with the Old Osage in northwestern Allen County. The exact route and position of this northern tributary is unknown. It was later captured by headward erosion of an eastward-flowing stream, such as the ancestral Grand River of northwestern Missouri.

The ancestral Arkansas River is also represented in Figure 25. The ancestral Arkansas River flowed eastward across Butler and Greenwood Counties, and likely joined with the Old Osage River in southeastern Woodson County (Aber 1992). The Arkansas River was later dismembered by headward erosion of the Walnut River in Butler County (Aber 1992).

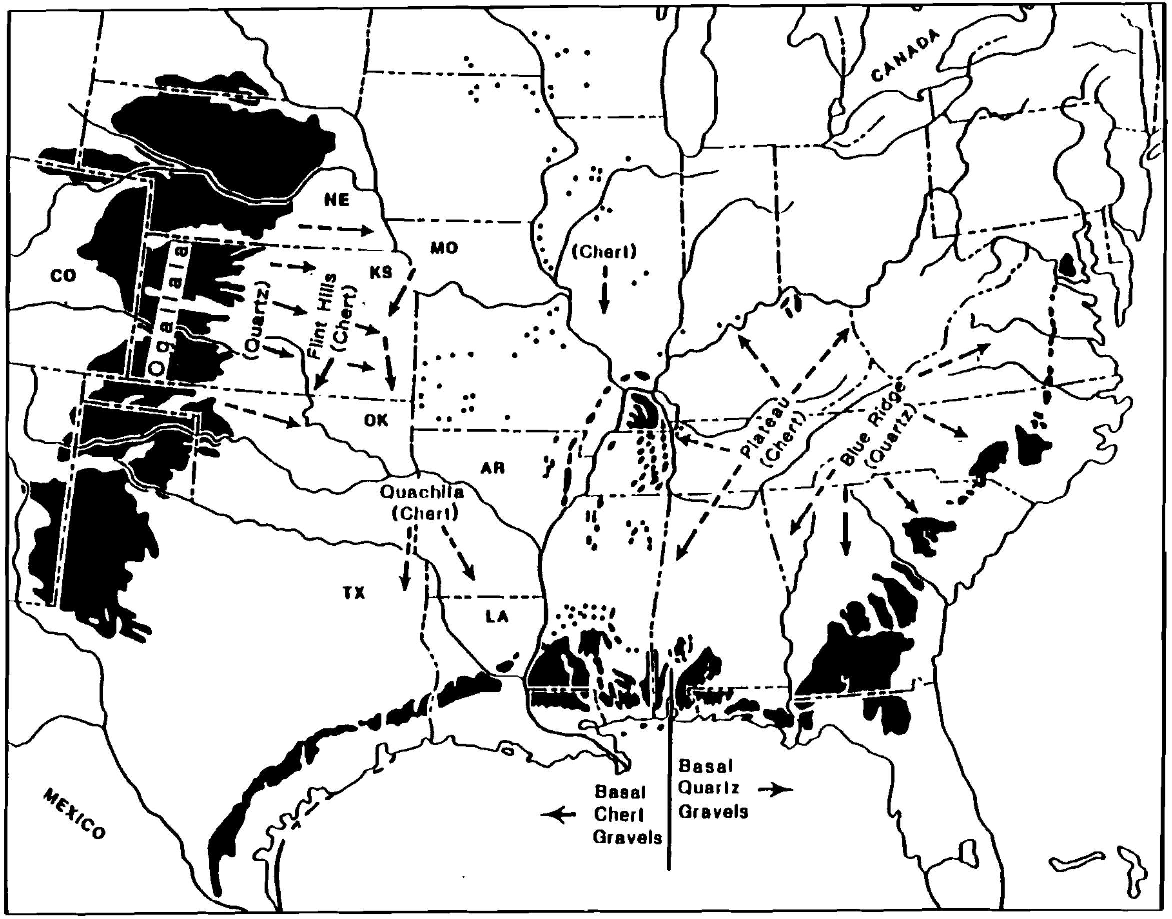

Figure 25. Map showing the distribution and sources of Tertiary gravels in the eastern United States. Drainage routes are of different or uncertain ages. Kansas portion modified from Kesel (1989, pers. com.), based on interpretations of this study and Aber (1992).

CHAPTER 5. CONCLUSIONS

This study has reached the following conclusions:

1. The asymmetrical preservation pattern of upland gravels in Chase County is similar to that found in other counties of east-central Kansas.
2. Subsurface fractures in Chase County have influenced the orientation of drainage development in the county.
3. Deformed strata have influenced drainage development in Chase County.
4. The main stem of the Old Osage River flowed across southern Chase and Lyon Counties. In southern Coffey County, the main stem joined with a tributary whose route paralleled the route of the modern Cottonwood and Neosho Rivers of Chase and Lyon Counties.
5. The Old Osage River exited the state in a manner similar to the modern Neosho River.
6. A northern stream or tributary of the Old Osage River may have joined with the main stem of the Old Osage in the vicinity of southwestern Anderson County or northwestern Allen County.

The information concerning the location and coverage of upland chert gravel (Olpe Soil) may also aid in determining alternative sources of gravel for roads that would not disturb the habitat of the Neosho madtom by river dredging of gravel.

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APPENDIX OF COMPUTER FILES

(Disk in pocket on p. 63)

Data Type:	Viewing Module	File Name	Palette
1. Cottonwood Limestone elevation data (raw)	use TOSCA type TOSCA at C:IDRISI prompt	COTLSEL	(none)
2. Chase Co. gravel elevation data (raw)	COLORa	CHRTELV	(default)
3. Chert gravel data eastern Kansas (raw data)	COLORa	CHERT	(default)
4. Chase Co. gravel elevation data (classified)	COLOR	CS-CHERT	SPECT2
5. Figure 23. Cottonwood Limestone elevations	COLOR	COTLSELV	COTPAL
6. Reclassified chert gravel data eastern Kansas-15 m interval	COLOR	KS-CHERT	OLPEPAL

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