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Expression of Regional Structural Trends in Surface
Features and Geology of the Hepler a
and Western Hiattville Quadrangles, Southeast Kansas

by

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EXPRESSION OF REGIONAL STRUCTURAL TRENDS IN SURFACE FEATURES AND GEOLOGY OF THE HEPLER AND WESTERN HIATTVILLE QUADRANGLES, SOUTHEAST KANSAS

by

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ABSTRACT

Identified regional subsurface structures in southeast Kansas exhibit strong preferential orientation to both the NNE and NW. Previous investigators believe these trends to be the result of late Phanerozoic fracturing of the midcontinent crust into suborthogonal blocks, the boundaries of which are thought to persist as crustal weak zones. More recent deformation has occurred as the blocks have jostled in response to tectonic forces acting on the continental margins. Detailed geologic mapping of the Hepler and western Hiattville quadrangles in southeast Kansas, using both traditional field techniques and satellite imagery interpretation, identifies small-scale structures visible at the surface that align with identified trends of the subsurface. Gentle surface structures are visible on structure contour maps prepared using contacts exposed at the surface. When compared to structure contour maps based on points derived from well data of strata in the subsurface, surface features closely approximate structures seen at depth. Subsurface structure also potentially impacts the modern drainage pattern.

Prior to completion of the traditionally constructed geologic map, I prepared a geologic map based on satellite imagery interpretation and a brief field survey. Comparison of the two maps revealed deficiencies in the imagery based product. Several of the lithostratigraphic units were not visible and contacts were not accurately located. Satellite imagery, while a useful tool in understanding the general geologic setting regionally, is too limited in its spatial resolution for use in identifying the small-scale features of interest in this study. Thick soils, heavy vegetation and the small size of structural features all act to limit the utility of currently available satellite imagery for this purpose in southeast Kansas. The most reliable approach for identifying surface features

and understanding their relationship to regional, subsurface trends remains the traditional field technique of generating geologic maps and the careful analysis of data gathered during this process.

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ACKNOWLEDGMENTS

A project of this type requires collaboration by many professionals who are willing to give much of themselves and their time to the student in their care. This project would not have been possible without the efforts of Dr. Mary Hubbard. Not only did she locate a source of funding to support my research during the summer of 1997, she worked with fellow members of the geology department to procure a high quality computer, peripherals, software and data for my use. Dr. Ron West and Mr. Bob Sawin accompanied me to my study area to help me learn the general lay of the land and familiarize me with the well-concealed rocks of Bourbon and Crawford Counties. Dr. John Harrington assisted this neophyte with the image processing and interpretation that were to prove invaluable to the study. Dr. Jack Oviatt, head of the Kansas State University Geology Department, gave me a job and opened scholarship opportunities to me. Dr. Allen Archer convinced me that pursuing a Master of Science degree was a good idea, in the first place and he helped to get the computers and software up and running. Dr. Sy Seyler, of the Geography Department, allowed me unrestricted access to his computer lab and the invaluable printers and plotters it contained. Brock Emert helped convert squiggly lines on mylar to ARCINFO coverages. To these professionals, and many others, I owe a debt that I may not easily repay.

Although these contributions were key to my success, I owe a special thanks to my family. My wife, Carla, sacrificed a great deal for me to return to school after graduating from Oklahoma State University over fifteen years ago. She supported my decisions and helped keep me working toward my final goal. My children, however, win the award for outstanding assistance. During each of my six trips to southeast

Kansas, one or both would accompany me to keep the 'old man' out of trouble. Due to my disability, I may not have made some of the long walks back to the truck without their presence and help. We all have fond memories of the hordes of ticks and horrific undergrowth along the creeks. None of us will never forget the day my son stepped on the copperhead. To Meagan and Keith, I can only say "thank you". This work is dedicated to you both.

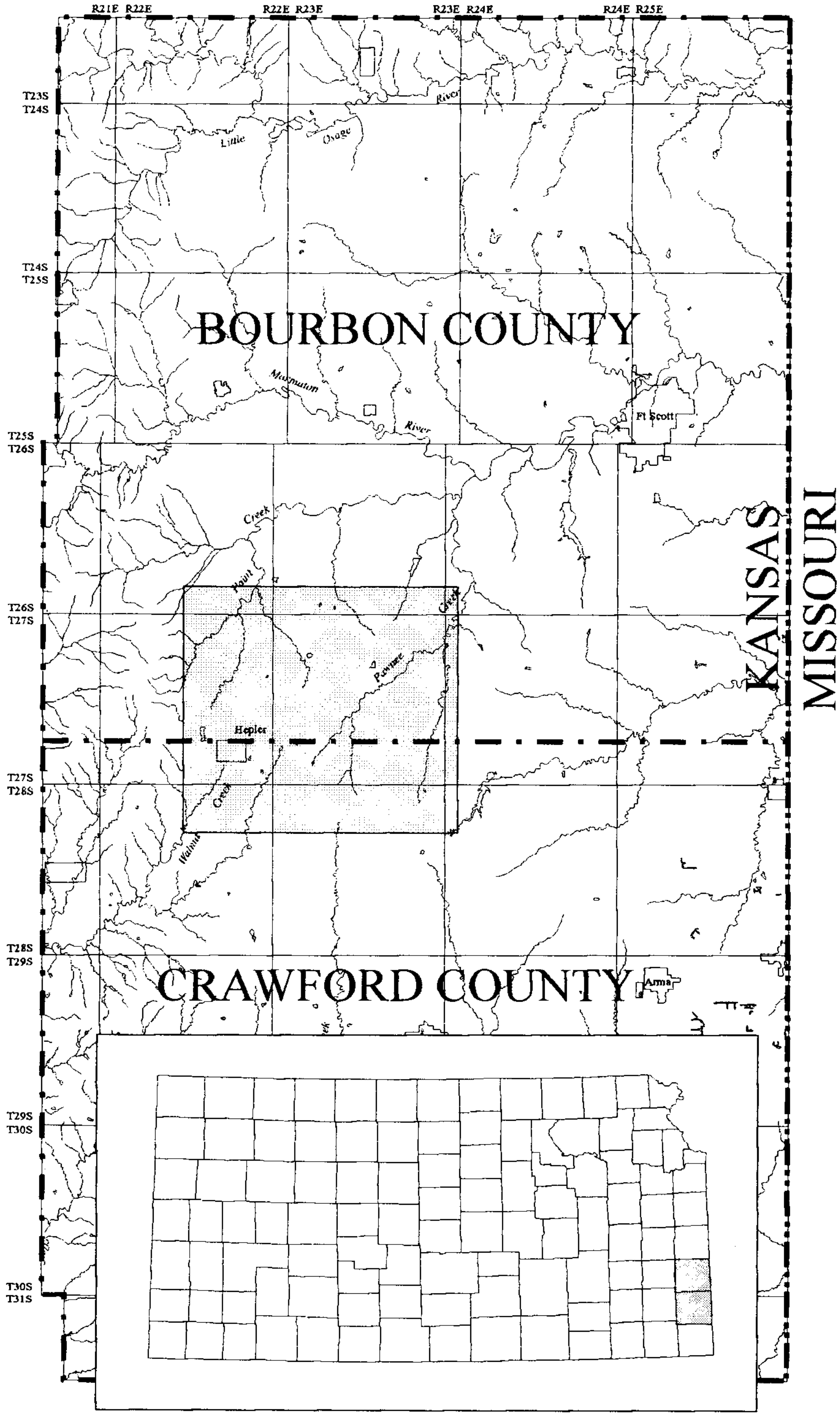
INTRODUCTION

Geology of the North American midcontinent can be characterized as a sub-horizontal sequence of mostly marine, Paleozoic sedimentary rocks unconformably over-lying a crystalline basement that has a potentially complex, but poorly understood structure. The geometry of the basement structure has been influenced not only by Phanerozoic mountain building events along its margins, but also by Precambrian rifting and coalescing of tectonic plates and assorted shifting that accommodated stresses developed as tectonic movements have been borne out through history. Only in the shield regions of the northern United States and Canada is the basement itself exposed. In the majority of the midcontinent region, this foundation is covered by what can be considered a thin veneer of younger strata. This thin layer may contain clues about the structures concealed in the basement beneath.

The midcontinent has yielded vast amounts of valuable rock and mineral resources. From basic building stones and matrix to enormous fossil fuel reservoirs, this region of North America has fueled the economic and cultural development of the Canadian and American heartland. Although new deposits become seemingly more difficult to locate, the possibility remains that much of this region's wealth may be undiscovered. By studying subtle features of the overlying strata, current investigators may be able to glean information about the deeper structures concealed beneath. A more complete understanding of subsurface geometry will greatly assist in the effort to unlock the secrets of the remaining untapped riches of the midcontinent.

The purpose of this study is to use both field and satellite imagery based mapping techniques to better understand the geometry of structures in the sedimentary cover and to relate them to structural trends identified in the subsurface by previous investigators. Several steps were followed in pursuit of this objective. First, a study area with identified pre-existing deep structures was chosen. Second, a detailed geological map of the study area was prepared. This process was aided using satellite imagery. Third, a structure contour map of a lithostratigraphic contact that is exposed at the surface and projected to shallow depth was constructed. Fourth, a subsurface structure contour map was completed, based on data from well logs and regional structure contour maps (Blair and Berendsen, 1992). Finally, structures identified on surface and subsurface maps were compared. Results of the study are based on this evaluation. A secondary objective was to compare geologic maps made using satellite imagery and traditional field methods in an effort to assess the accuracy of geologic mapping using imagery alone in the study area. Additionally, global positioning satellite (GPS) technology was used during field mapping.

The study area is located in southeast Kansas, straddling the Bourbon and Crawford County boundary (fig. 1). Map coverage of the area includes the Hepler Quadrangle and the western third of the Hiattville Quadrangle. Rocks outcropping here are Missourian and Desmoinesian aged Pennsylvanian strata. The sedimentary cover in this region is approximately 1600 feet thick and the total relief across the study area is approximately 210 feet. Regional dip is approximately ten feet per mile to the west.



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Pawnee
Creek
Hepler
Creek
Walnut
KANSAS
MISSOURI
CRAWFORD COUNTY
Arma

GEOLOGIC SETTING

Paleozoic strata of the midcontinent rest unconformably on a crystalline basement ranging from 1.5 to 3.6 billion years in age (Van Schmus, 1992). The midcontinent is characterized as that portion of the craton that has not been subjected to repeated, Phanerozoic tectonic deformation, as has occurred in the continental margins. The midcontinent is divided into two broad provinces: the Canadian Shield, where igneous and metamorphic rocks are exposed at the surface, and the Platform, where a relatively thin layer of Paleozoic sedimentary rock covers the basement. The midcontinent is bounded on the south and east by the Ouachita/Appalachian Orogenic Belt and on the west by the Cordilleran Orogenic Belt (Levin, 1994).

The oldest known basement structures in the midcontinent region are relics of the original process that formed the craton. This process involved the accretion of existing terranes to the margins of the original North American core. The craton grew as progressively younger provinces were sutured to the edges of the continent as plates merged throughout Archeon and Proterozoic time, with the final member added approximately 1.7 billion years ago (Hoffman, 1989). As a result of these repeated collisions and separations, the fabric of the midcontinent basement was fractured into regional-scale, sub-orthogonal blocks whose boundaries have persisted as fault zones or flaws through modern time (Marshak and Paulsen, 1997). The orientation of these zones is in two primary directions: NE to SW and WNW to ESE (fig. 2). As stress fields changed over time, movements occurred along these pre-existing fault zones, often interpreted as reactivations of older faults. One of the most dominant basement structures in the midcontinent is the midcontinent rift (MCR) which is a continuous, broad, arc-

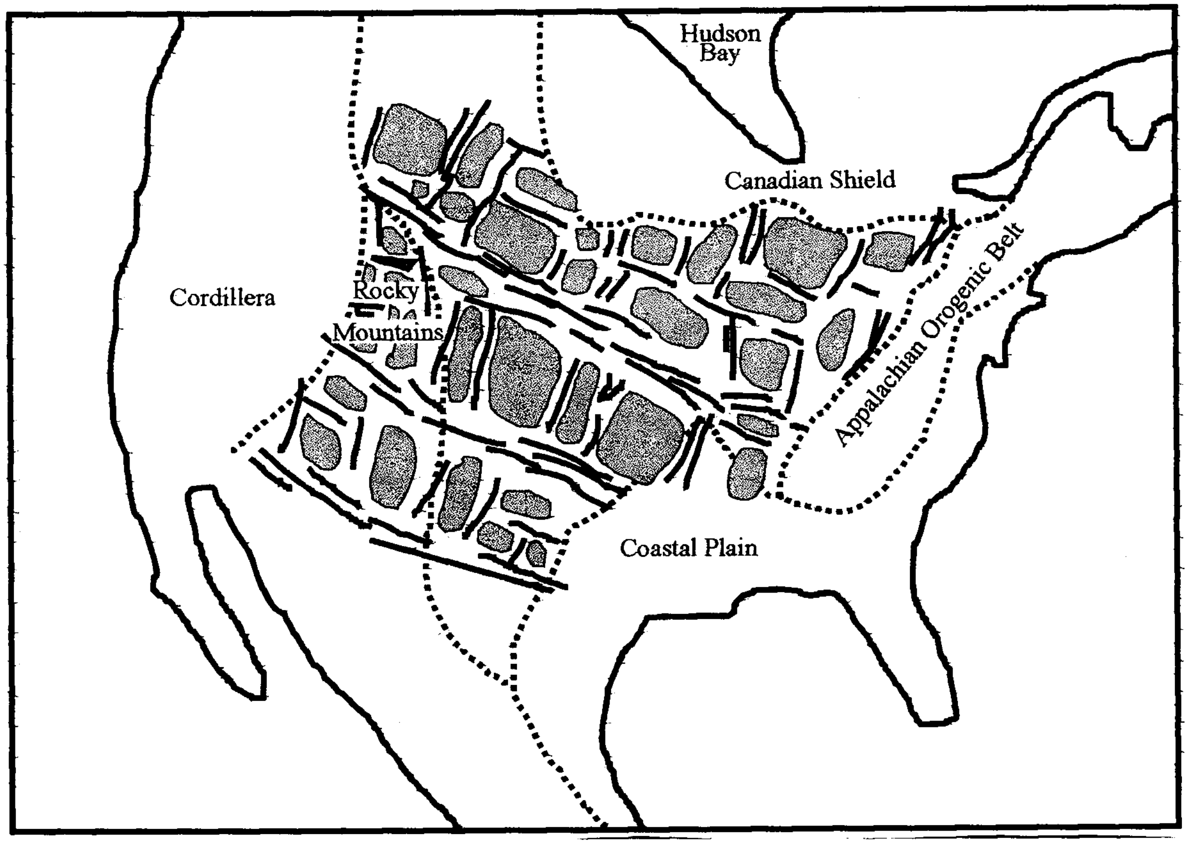


Figure 2. Sketch illustrating the division of the continental United States into upper crustal blocks bounded by midcontinent fault-and-fold zones (modified from Marshak, 1997).

shaped anomaly extending from Lake Superior region into central Kansas (fig. 3). The MCR is a highly visible feature on gravity and aeromagnetic surveys of the central United States and has also been referred to as the Midcontinent Gravity High (Van Schmus, 1992). It is interpreted as a former rift boundary which opened as compressional stress eased approximately 1.1 billion years ago, during the Grenville Orogeny, and then closed, or inverted, as compression resumed approximately 30 million years later (Cannon and Hinze, 1992). The Grenville Orogeny was the product of the collision of the North American and Northern European (and possibly African) plates in mid Proterozoic time, along the region which is now the entire eastern seaboard and Gulf of Mexico (Levin, 1994).

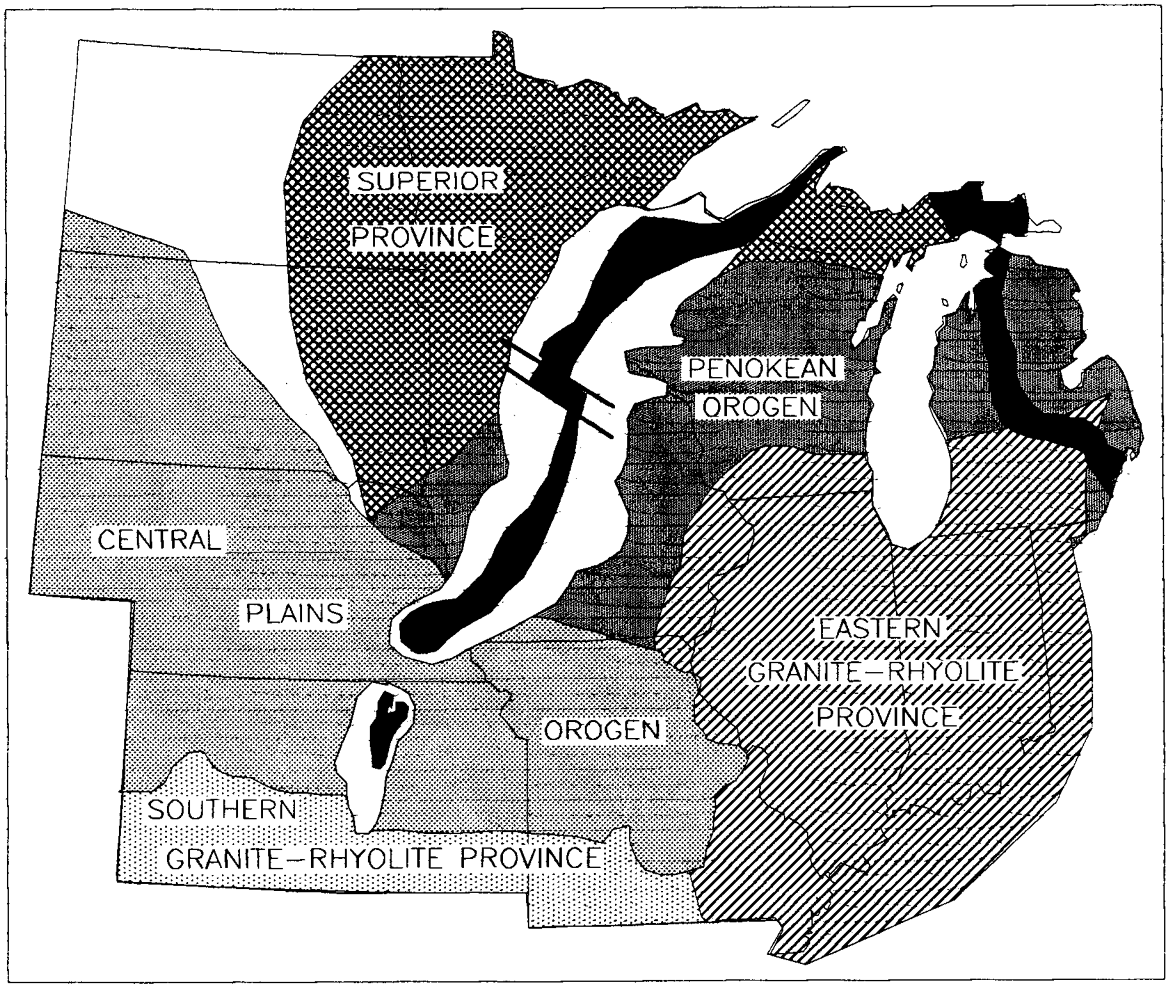


Figure 3. Tectonic framework of the midcontinent region showing the midcontinent rift (MCR) in black and other major basement provinces. The axial portion of the MCR is dominated by mafic intrusives (modified from Van Schmus, 1992).

With the main body of the craton formed by latest Precambrian time, major tectonic deformations of the Phanerozoic shifted further toward the continental margins. Stresses that built up along the margins, however, were transmitted to the more stable interior. As stress was redistributed inland the craton's orthogonal upper-crustal blocks shifted and jostled in response. Baars (1992) considered much of this movement to be rotational in nature, which converted many of the preexisting block type faults, created by alternating compression and extension, into wrench faults, particularly in Kansas. Today, even with no current active tectonism on the eastern continental margin, the stress field within the North American plate is adequate to generate seismically detectable readjustments of the crustal blocks within the craton. Seismic events in the midcontinent, such as activity along the New Madrid Fault Zone, plot along well defined linear trends, thought to identify the boundaries of these blocks (Marshak and Paulsen, 1997).

In middle to late Ordovician time, the eastern North American plate converged upon and collided with westward moving island arc terranes. Initially, this impact was centered along the northeastern seaboard initiating the complex deformation and metamorphism of sedimentary rocks previously deposited in the passive margin region. This event, known as the Taconic Orogeny, signaled the initiation of a lengthy era of compression along the eastern continental margin as the Proto-Atlantic, Iapetus Ocean, closed. This compressional stress, punctuated by intervals of extension would continue into the late Permian.

The Acadian Orogeny of mid Devonian time further deformed the eastern continental margin. This stage of continued compression resulted from the oblique convergence of a continental fragment along the eastern edge of the North American plate (Levin, 1994). Also, in late Devonian time, compressional forces began building on the western continental margin. The Antler Orogeny, in the west, occurred as an eastward moving island arc complex struck the craton along its western coast.

Tectonism in the east reached its zenith in the late Pennsylvanian and early Permian. South America and Africa collided with the southeastern portion of North America and Europe causing the Allegheny Orogeny, which formed the Appalachian Mountains of the United States. As the super-continents continued to coalesce into Pangea, stress began shifting further west along the southern boundary of North America causing the uplift of the Ouachita Mountains, which extend from the southern end of the Appalachians to the west from Arkansas into Texas. Farther west, the Ancestral Rockies formed. Large slabs of the continental crust were up-thrown. Acting as a counter-balance inland, large portions of the craton were downwarped creating, among others, the Anadarko and Arkoma Basins of Texas, Oklahoma and Arkansas.

Compressional forces gradually gave way to extension as Pangea began breaking up in the early Triassic. The modern Atlantic Ocean formed as North America and Europe slowly drifted apart. Even as extension dominated the east, compression built in the west as the formerly passive western margin gave way to an active subduction zone that consumed eastward moving oceanic crust. The Sevier Orogeny resulted in a 100 kilometer shortening of the western craton boundary as thrust faults formed in response to compression in early Triassic time. The subsequent Sonoma Orogeny in the mid-Triassic resulted from the additional stress that built up due to terrane accretion on the western continental margin.

As western North America overrode oceanic crust, tectonic disturbances shifted further east away from the continental margin. The resultant Laramide Orogeny of the late Cretaceous and early Tertiary time formed the modern Rocky Mountains and uplifted large blocks of continental crust. Continued activity has occurred throughout the western United States with active volcanism in the Cascades and tectonic disturbances along the San Andreas Fault today.

While the continental margins were active through much of the Paleozoic, the midcontinent was more stable. Eiperic seas inundated the interior regions of the craton, forming a series of alternating carbonate and shale deposits. Repeated fluctuations of sea level caused the deposition of cyclic shale/carbonate sequences, or cyclothems (Heckel, 1991), which are attributed to the continuous regressions and transgressions sweeping across the midcontinent platform. Although significant mountain building events did not occur in the midcontinent region, the existing network of crustal blocks and numerous aligned faults did allow the transmission of stress into the more stable interior. Thus, the structural fabric of rocks in the midcontinent could be influenced by events that occurred hundreds or even thousands of miles away.

Several structural trends currently exist in rocks of the midcontinent. In Kansas, the Precambrain basement structure is dominated by conjugate northeast and northwest trending wrench fault zones (fig. 4). Faults of the midcontinent rift cut across eastern Kansas from NNE to SSW and into central Oklahoma (Baars, 1992). Another prominent basement trend consists of faults crossing the midcontinent rift almost at right angles, oriented NW, comprising the Bourbon Arch in eastern Kansas and the Central Kansas

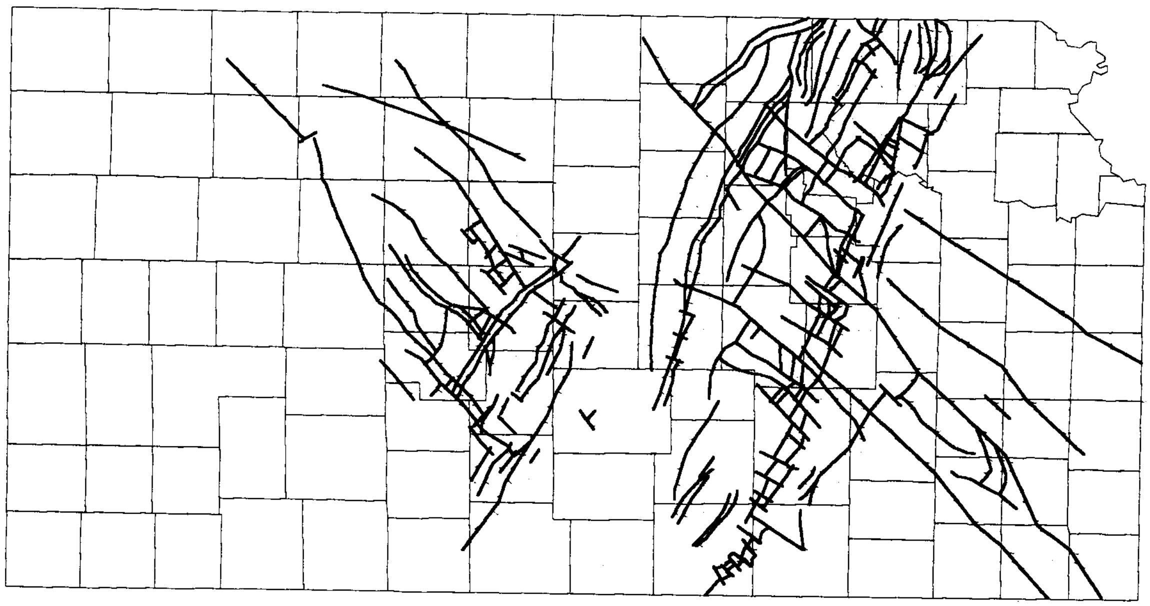


Figure 4. Generalized map of the major Precambrian basement faults in Kansas. These faults are identified through the study of surface trends and from subsurface studies. North-northeast trending faults are believed to be sinistral strike-slip faults while northwest trending structures are interpreted as dextral strike-slip faults (modified from Baars, 1992).

Uplift further west. As a result of these fault zones, Kansas is divided into numerous sub-orthogonal crustal blocks, as is the midcontinent basement.

As noted earlier, the general basement fabric was established in the late Precambrian as conditions on the continental margins led to various orogenic events. The interior was not unaffected. Responding to transmitted stress, the interior region's preexisting network of faults or flaws reactivated in accommodation (Baars, 1992). From late Mississippian to early Pennsylvanian time, as the Ouachita uplift was tectonically active, several regional structures formed in Kansas. The Nemaha Uplift of north central eastern Kansas and the Central Kansas Uplift were raised as major positive tectonic elements in response to compression from the east and south (Newell, 1995). These uplifts serve to define five basins that extend from Kansas into neighboring states: the Hugoton Embayment of the Anadarko Basin and the Sedgwick, Salina, Cherokee and Forest City basins (fig. 5).

By the beginning of mid Pennsylvanian time, South America and Africa had collided with North America. Renewed tectonic activity reactivated the faults of the Bourbon Arch and the Nemaha and Central Kansas uplifts again as the Ancestral Rockies formed further southwest. The affect was to form shelves for the rapidly subsiding Anadarko and Arkoma Basins in Oklahoma and Texas (Baars, 1992). While both the shelf regions and the basins to the south were the sites of shallow marine and near shore sedimentation, the continued loading and subsidence in the Anadarko Basin resulted in the accumulation of over 40,000 feet of sedimentary rock.

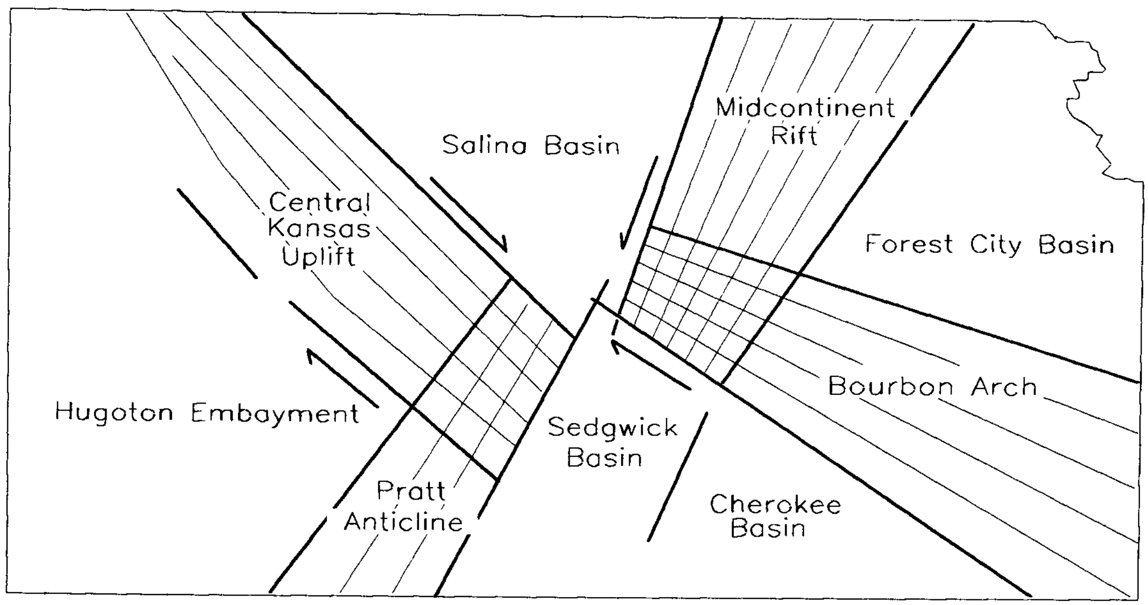


Figure 5. Highly generalized depiction of the major regional structures of Kansas. Heavy black lines indicate major structural fabrics and arrows indicate interpreted sense of movement. The fault zones form basement uplifts that divide the region into five Paleozoic depositional basins (modified from Baars, 1992).

Because sedimentation in Kansas was fairly continuous during much of this time, several of the newly forming basins were filled as rapidly as they subsided. As a result, lithostratigraphic units of wide lateral extent formed. The only noticeable change that occurred in these formations was a general thickening of facies basinward, without tremendous lateral variation of depositional environments. Particularly in the case of the Bourbon Arch, this is true. Lithostratigraphic units can be traced across the crest of this feature with only a general thinning occurring as the crest is approached (Merriam, 1963).

The study area sits atop the southern flank of the Bourbon Arch as it descends into the Cherokee Basin of southeast Kansas. Blair and Berendsen (1992) have identified several regional tectonic zones that dissect this part of the state and extend into neighboring regions (fig. 6). Predictably, these tectonic zones, in which Paleozoic strata are faulted and/or folded, align with the general basement geometry of dominantly NNE and NW trending structural lineations. These tectonic zones may have acted as the conduits for stress generated at the continental margins to be transmitted into the study area. Careful examination of subtle surface features may determine whether identified deeper structural trends are also present in the surface.

STRATIGRAPHY

Middle Pennsylvanian strata of the Desmoinesian Marmaton Group and Upper Pennsylvanian strata of the Missourian Pleasanton and Kansas City Groups are exposed in the study area along a general NNE to SSW line, with older strata in the eastern section of the outcrop belt (fig. 7). Regional dip is approximately ten feet per mile to the west.

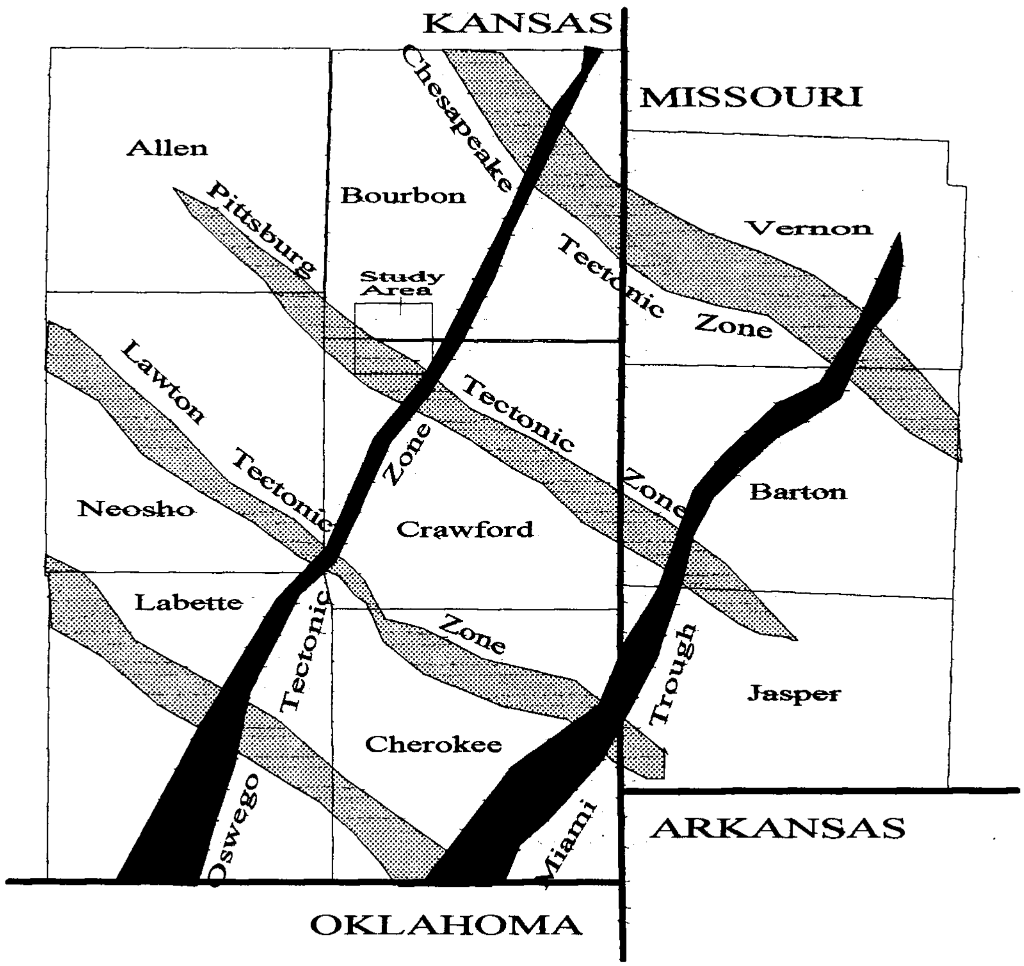


Figure 6. Major structural features in southeast Kansas and southwest Missouri. These zones are identified through the use of linear gravity and magnetic maps in conjunction with well data (modified from Blair and Berendsen, 1992).

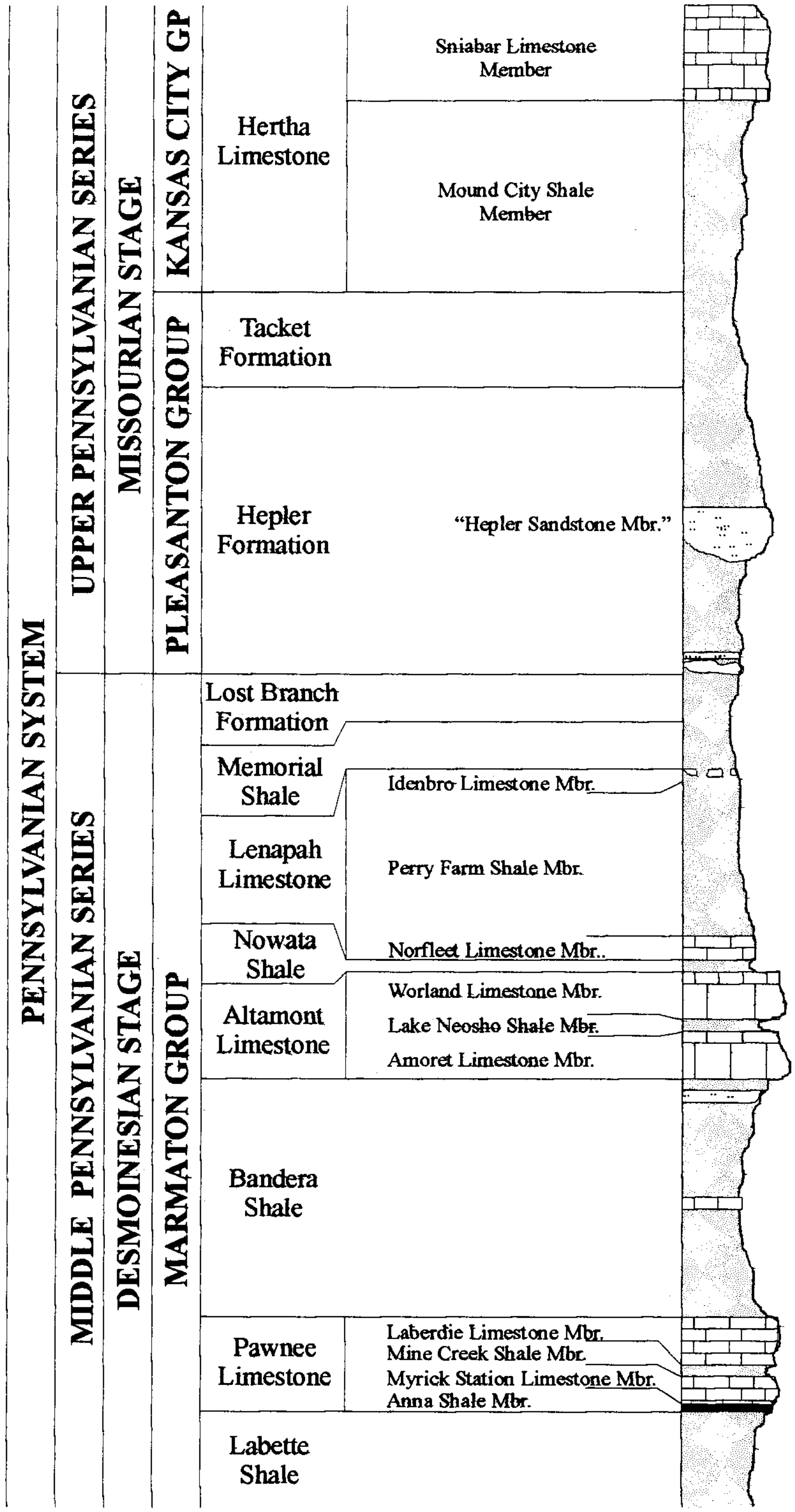


Figure 7. Stratigraphic column of the rocks exposed in the study area. Units are shown in proportion to relative thickness in the field (modified from Zeller, 1968 and Heckel, 1991).

Outcrop quality in the region is moderately good to poor due to the extensive soil development and agriculture in the region. The best exposures of bedrock are found occur in creek beds and in some road cuts. Exposure quality is best in the northwestern portion of the study area and in the south, outcrops are rare.

Sedimentary rocks exposed in the study area conform to the general cyclothem model initially proposed by Wanless and Weller (1932) and refined by Moore (1936), Heckel (1977,1991) and others. Carbonates and shales alternate in discrete packages related to relative sea level changes as late Paleozoic eiperic seas ebbed and flowed across the shallow midcontinent platform in a series of repeated regressions and transgressions. The net result of the cyclic sea level changes across the craton was the deposition of cyclic layers of strata dependent on the relative water depth, distance to source areas, climate and, to some extent, tectonics at the time of sedimentation (fig. 8).

Marmaton Group

The oldest lithostratigraphic units exposed in the study area are the formations and members of the Marmaton Group, representing the youngest rocks of the Desmoinesian Stage. Containing both marine and nonmarine facies, Rocks of Marmaton age crop out in a belt ranging from about 10 to 25 miles wide in eastern Kansas (Jewett, 1945) and extending into Oklahoma and Missouri. Traditionally, the top of the Marmaton Group has been marked by a regional unconformity separating the younger Missourian rocks above at the base of the Hepler Sandstone. This division has lately been called into question (Heckel, 1991). The boundary between the Marmaton and Pleasanton Groups

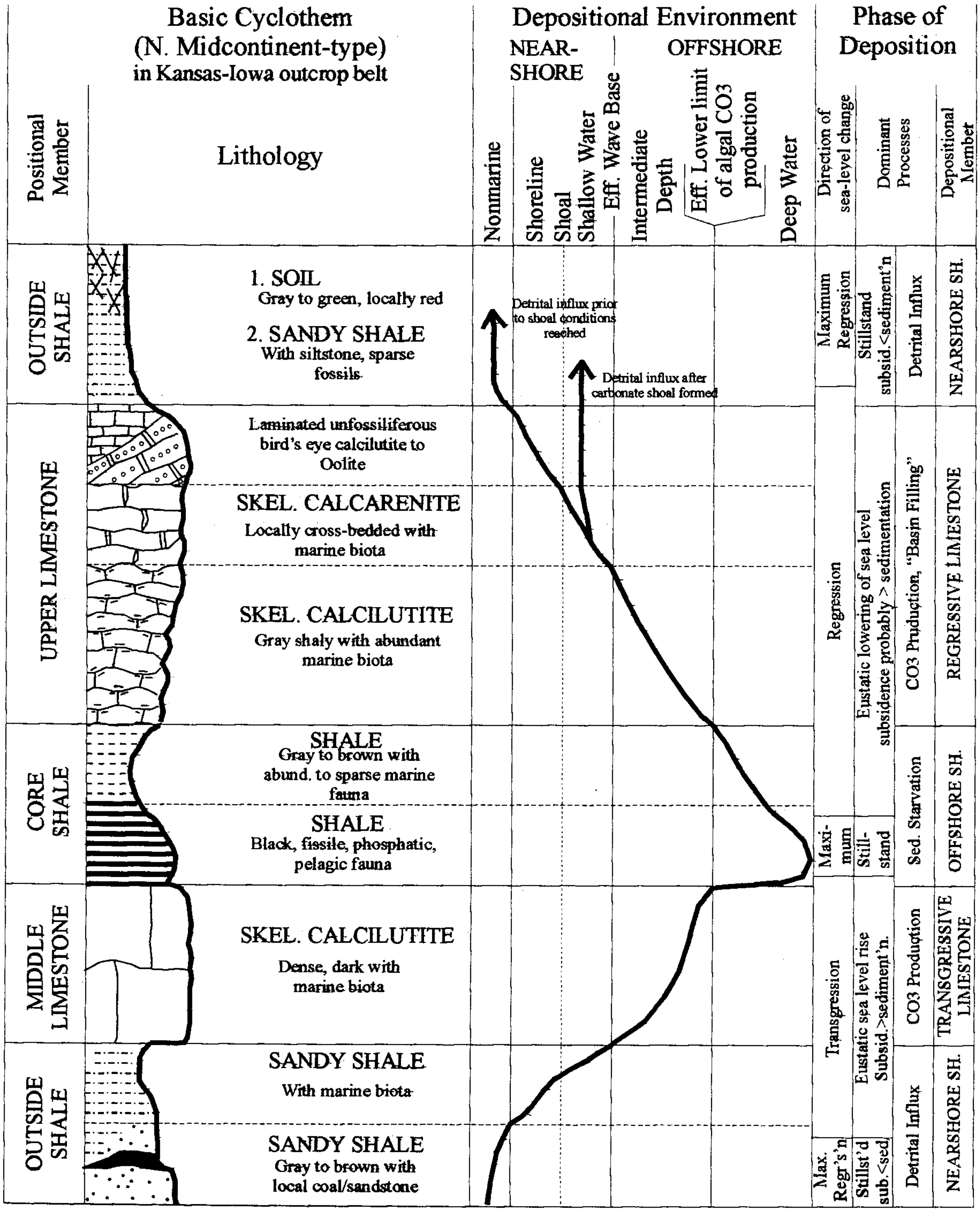


Figure 8. Basic vertical sequence of the individual "Kansas Cyclothem". Positional member terms derive from Moore (1936) for limestones and Heckel and Baesemann (1975) for shales (modified from Heckel, 1979).

has changed with the recognition of a new formation as the uppermost limit of the Marmaton.

Labette Shale

In the study area, the oldest exposed formation of the Marmaton Group is the Labette Shale, cropping out in the northeastern corner along the Pawnee and Little Pawnee Creeks. The type section for the Labette Shale, located in sec. 22, T.32S., R.20 E., near Labette in Labette County, Kansas, was designated by Haworth (1898). The Labette Shale is a sandy shale averaging approximately 25 feet in thickness in the study area. Non-persistent, fine grained, somewhat micaceous, lenticular sandstones are common in the upper part of the formation. Fresh surfaces of the shale are generally gray, weathering to light brown, with the sandstone weathering into reddish brown, characteristic of many of the sandstones exposed in the study area.

Pawnee Limestone

The Pawnee Limestone is exposed in the eastern third of the study area and is limited to the western Hiattville Quadrangle. As presently defined it is composed of four members: the Anna Shale, the Myrick Station Limestone, the Mine Creek Shale, and the Laberdie Limestone, in ascending order (Zeller, 1968). The type locality for the Pawnee Limestone is located at sec.7, T.27S., R24E. (Jewett, 1941). In the study area, neither the Anna Shale nor the Mine Creek Shale can be differentiated due to poor outcrop exposure. The topmost Laberdie Limestone forms prominent benches along its outcrop. When combined with the Myrick Station Limestone, the overall thickness of the Pawnee in the study area is approximately 20 feet. Both the Laberdie and Myrick Station are medium to dark gray on fresh surfaces weathering to light gray. The lower Myrick Station is somewhat thin bedded and commonly contains chaetetids along with crinoid fragments, brachiopods and some fusulinids. The younger Laberdie is generally lighter gray than the Myrick Station with massive bedding at the base and somewhat wavy, thin beds at the top. The Laberdie is not a highly fossiliferous rock, although it does contain chaetetids, some fusulines, echinoid and crinoid fragments, and brachiopods (Jewett, 1945). The top of the Laberdie frequently weathers into a pitted surface with brown blotches or stains. Where the Pawnee underlies the surface, soils are relatively thin and a hummocky terrain results.

Bandera Shale

The Bandera Shale is exposed in the central portion of the study area in both the Hepler and Hiattville Quadrangles. The formation was named by Adams (1903), however no single outcrop has been listed as the type exposure, rather, several localities in Bourbon and Linn Counties, Kansas, are noted as demonstrative of different facies within the Bandera. In the study area, the Bandera is approximately 50 feet thick. It is exposed along several of the major creeks and forms broad, flat pastures in some areas, and is exposed along Pawnee Creek in the east. The Bandera Shale is reddish-brown sandy shale that weathers to produce the distinctive reddish brown, clay-rich soils developed where it is exposed. A persistent 2 to 3 feet thick, very fine grained, somewhat micaceous, brown sandstone occurs near the top and can be observed at many outcrops throughout the study area. Additionally, a thin, dark gray to black limestone can occasionally be found near the middle of the formation.

Altamont Limestone

The Altamont Limestone is exposed in the central part of the study area. Although the Altamont forms topographic benches, they are not as prominent as those formed by the older, Laberdie Limestone Member. The formation's type exposure is located at Sec. 5, T.33S., R19E near the town of Altamont, Kansas (Jewett, 1945). The Altamont Limestone is composed of three members: the Amoret limestone, the Lake Neosho shale and the Worland limestone, in ascending order. In the study area, the Lake Neosho shale is quite thin and cannot be identified in outcrops of the Altamont. Absence of this middle member makes differentiation of the Worland limestone from the Amoret limestone exceedingly difficult. The total thickness of the Altamont in the study area is approximately 25 feet, of which, approximately 10 feet, is thought to be the Worland Limestone Member. The Amoret is massive with crinoid and brachiopod fragments throughout. It is coarsely crystalline, appearing dark gray on fresh surfaces, weathering to very light gray. The Worland is also massive in the study area, contains a similar biota of crinoids and brachiopods, is somewhat blue gray on fresh exposures and weathers light gray. The upper surface of the Worland frequently exhibits a micro-karstic texture. The best exposures of the Altamont Limestone occur along Paint Creek, near the northern edge of the study area, where numerous large slump blocks bound the eastern bank, forming cliffs approximately 15 feet high.

Nowata Shale

The Nowata Shale is exposed in only two known locations in the study area where it is seen in contact with the underlying Altamont Limestone (NW ¼, NE ¼, NE ¼, and NE ¼, NE ¼, NW ¼, Sec. 12, T.27S., R.22E). At these exposures it is 3 feet thick and quite sandy. Fresh surfaces are gray, weathering light brown. Several thin (less than 6 inches thick) lenticular sandstone layers are seen in outcrop. The type locality is located near the town of Nowata, Oklahoma. The Nowata Shale has been documented to vary in thickness from 0 to 50 feet (Jewett, 1945).

Lenapah Limestone

The Lenapah Limestone Formation overlies the Nowata Shale and consists of three members: the Norfleet limestone, the Parry Farm shale and the Idenbro limestone, in ascending order. The type exposure is in the NE ¼, Sec. 30, T.28N., R.16E., in Nowata County, Oklahoma (Jewett, 1945). The Lenapah can be traced across Kansas into Iowa. In the study area, the Norfleet is fossiliferous and massively bedded, averaging approximately 18 inches in thickness and forms most of the stream bed of Prong Creek in the northwest part of the study area (Sections 3 and 10, T.27S., R.22E.) and is thus well exposed. It is dark gray on fresh surfaces, weathering to light gray, and contains crinoids and brachiopods in abundance. The upper surface is frequently nodular and weathers in an irregular pattern of small knobs. Three units are recognized within the Perry Farm shale. The lower 3 feet is characteristically a dark gray, fissile shale. The middle 7 to 8 feet is a sandy shale, that becomes sandier upward, with thin lenses (less than 6 inches) of sandstone and dark gray limestone. In outcrop, this unit weathers light brown, making it easy to separate from the lower unit. The upper 5 to 6 feet are locally a persistent, fine grained, reddish brown, laminated siltstone/sandstone, containing minor amounts of mica. Some of the sandstone layers are over 2 feet thick. The Idenbro limestone is present only as a layer of carbonate nodules occurring above the sandstone of the Perry Farm shale (Heckel, 1991). Nodules recovered from an outcrop along Prong Creek are oblong averaging approximately 2 inches in length and ½ to 1 ¼ inches in diameter.

Memorial Shale

Named for its type section near Memorial Park Cemetery in Tulsa, Oklahoma (Jewett, 1945), the Memorial Shale was originally the uppermost formation of the Marmaton Group, which terminated at the lower contact of the Hepler Sandstone Member. This has recently changed as the Memorial Shale has been subdivided into two formations (Heckel, 1991). This formation is very poorly exposed in the study area. Based on the description of the Prong Creek core located approximately 1 mile west of the study area (Sec.5, T.27S., R.22E.), Heckel described the formation as being 8.6 feet thick and gray in color (1991). The Memorial contains a 1.2 feet thick argillaceous siltstone at its base and the remainder is a gray shale with scattered plant fragments and silty laminae.

Lost Branch Formation

Heckel (1991) separated the Lost Branch Formation from the remainder of the Memorial Shale based on its more marine characteristics. Notably, the presence of the black, phosphatic, informally named Nuyaka Creek shale bed (Bennison, 1981) and is inferred to represent the deepest marine environment in the cyclothem model. Although this subdivision is an understandable differentiation in petrographic terms, it presents the geologist with a distinct challenge when identifying lithostratigraphic units in the field. The contact between the Memorial and Lost Branch Formations is a shale/shale contact. The Lost Branch is gray as is the underlying Memorial. In the study area, the Lost Branch Formation is not exposed. The type section is located in the NE ¼, NE ¼, NE ¼, Sec. 10, T.33S., R18E. The Prong Creek core indicates that the Lost Branch Formation is 8.2 feet thick in the study area (Heckel 1991). The upper 6.9 feet is gray silty shale and the lower 1.3 feet is the Nuyaka Creek shale bed, a black, phosphatic, marine shale with a thin limestone near the base.

Pleasanton Group

The Pleasanton Group is a sequence of rocks composed primarily of shale with lesser amounts of limestone and sandstone (Jewett, et. al., 1965). The lower boundary of the Pleasanton Group is thought to be the division between the Missourian and Desmoinesian Stages in Kansas. The upper limit occurs at the base of the overlying Hertha Limestone (base of the Kansas City Group). The stratigraphy of this sequence has been revised several times. Traditionally, the lower member of the Pleasanton has been the Hepler Sandstone Member, which was thought to represent the unconformable contact separating Missourian from older strata. This concept has been challenged by recent investigators (Heckel, 1991) and new units have evolved.

Jewett and others (1965) divided the Pleasanton Group into the Tacket Formation, Checkerboard Limestone and Seminole Formation (in descending order). The basal Hepler Sandstone Member was included in the Seminole Formation. Jewett (1940) designated the type section of the Hepler Sandstone at the center of sec. 14, T.27S., R.22E. Careful examination of this outcrop (which is now badly deteriorated) and correlation to exposures in the immediate vicinity reveal this locality to be an exposure of the sandstone near the top of the Perry Farm Shale Member of the Lenapah Limestone (Heckel, 1991). This sheds doubt on the existence of an identifiable unconformable contact between Missourian and Desmoinesian strata in the study area.

In 1991, Heckel proposed that the entire sequence of terrestrial rocks above the Lost Branch Formation be named the Hepler Unit (Formation), a designation which was adopted by the Kansas Geological Survey. A marine shale overlying the Hepler Formation and terminating upward at the apparent interval of the Checkerboard Limestone was named the South Mound Shale. The remaining upper sequence was left as the traditional Tacket Formation that terminated at the base of the Kansas City Group. Whether inadvertent or not, Heckel also referred to a new boundary forming the base of the Hertha Limestone. In the past, the Critzer Limestone Member was the lower-most unit of the Hertha Limestone and Kansas City Group. In the Prong Creek core, Heckel (1991) identifies the Critzer Limestone as underlying the Upper Pleasanton shale unit.

As a further complication, the most recent geologic map of Kansas (Ross, 1991), refers to a newer subdivision of strata in the Pleasanton Group interval. The Hepler Formation remains at the base of the group, but the remaining Tacket Formation and Checkerboard Limestone have disappeared in favor of the recently named Shale Hill Formation.

Hepler Formation

The Hepler Formation is very poorly exposed in the study area. A few exposures occur in the extreme northwest corner of the study area where a persistent sandstone caps a series of high bluffs in Sections 3 and 10, T.27S., R.22E. This bed is approximately 5 to 6 feet thick and is composed of very fine grained quartz sandstone with minor amounts of mica. The sandstone is reddish brown and friable and forms several small waterfalls in Section 34, T.26S., R22E. and Section 3, T.27S., R.22E. In these waterfalls, up to 5 feet of the underlying gray, fissile shale is exposed. Based on the Prong Creek core, Heckel

(1991) described the entire Hepler Formation as 58.9 feet thick of mostly gray siltstone and mudstone. Sandstones exposed on the bluffs and in the waterfalls correlate with a sandy zone approximately 37 feet above the base of the formation. This zone is 16 feet thick with gray micaceous sandstone that is locally rippled and contains thin silty/shaly interbeds and scattered plant fragments.

Tacket Formation

The Tacket Formation is not exposed in the study area. The Prong Creek core contains 14.4 feet of gray to dark gray shale overlying the Hepler Formation. Heckel (1991) identified the base of this interval at the Exline Limestone, a 0.7 feet thick interval containing two thin limestones separated by dark gray shale. This marker layer was not found in the study area.

Kansas City Group

Only the lowest members of the Missourian Kansas City Group are exposed in the study area. Thick beds of limestone separated by intervening shale units characterize the Kansas City Group. These are laterally extensive and can be traced great distances into western Kansas, Oklahoma, Missouri, Nebraska and Iowa.

Hertha Limestone

The Hertha Limestone, at the base of the Kansas City Group, forms a conspicuous ridgeline extending across western Bourbon County before disappearing in northwest Crawford County. In the study area, only two members are present: the Mound City shale and the Sniabar limestone, in ascending order. The Mound City a is dark gray, fissile, marine shale approximately 45 feet thick. Several poor exposures occur along the eastern slopes of the ridgeline in Sec. 3, T.27S., R.22E. The best exposure of this member near the study area occurs in the spillway of the Bourbon County State Lake at SE, SE, NW, Sec. 12, T.26S, R.21E., approximately 4 miles northwest of the northwest corner of the study area. The Sniabar is the cap rock of the impressive ridge that snakes across western Bourbon County and forms the crest of the highest terrain in the northwest corner of the study area. The Sniabar is light gray, highly fossiliferous limestone that weathers light gray to white and is approximately 15 feet thick in the study area.

METHODS

To determine whether surface features reflect trends identified at depth, I completed three steps. First, I prepared a geological map of the study area. Next, using data derived during production of the surface map, I created a structure contour map of the most widely exposed lithostratigraphic contact (base of the Altamont/ top of the Bandera) in the study area. Finally, I prepared a subsurface structure contour map of the top of Mississippian strata using electric well logs, driller's logs and regional maps of southeast Kansas prepared by previous investigators. I have used English units of measurement because the base maps for this work are scaled in feet and miles.

Geological Map Preparation

Because the Hepler and Hiattville quadrangles do not have geological maps on file at the Kansas Geological Survey, I prepared a geologic map of the study area from scratch. Beginning in January and ending in August, 1997, I used traditional field mapping techniques in the preparation of this product. I visited and documented one hundred twenty six field sites during this process (Appendix A).

Upon locating a lithostratigraphic contact in the field, I would immediately determine how far it could be laterally traced on the surface. Typically, contacts were exposed only in isolated locations and could not be traced more than a few feet due to extensive soil and vegetative cover. To project the contact from one outcrop to another, I worked under the assumption that the rocks were largely flat lying and that contacts would parallel contour lines. In areas that bedrock was not exposed, I looked for indirect indicators of the underlying strata. Soil color and float exposed on the surface of cultivated fields and around farm ponds assisted me in determining the location of contacts. I further assumed that units within the study area maintained fairly uniform thickness with no dramatic changes.

Field work and final products are based on 1:24,000 scale, USGS 7 ½ minute quadrangles of the study area. Global positioning satellite (GPS) technology assisted in precisely locating exposures that were located away from readily identified terrain features and landmarks. In lieu of using aerial photographs as an aid, I procured satellite imagery to provide vertical views of the study area. This led to the formation of a secondary research objective. I prepared an additional map, based on the use of image interpretation principles (i.e. tone, texture, pattern, etc.) and a brief field survey. I later compared this map to the results of detailed field reconnaissance.

Satellite Imagery

I selected LANDSAT Thematic Mapper (TM) imagery, dated December 20, 1986, for use in this project due to the minimal cloud cover and "leaf off" winter vegetation conditions. All image processing was accomplished using version 8.2 of ERDAS Imagine (ERDAS, Inc., 1996) software on an IBM™ compatible Pentium™ 200

MHz computer under a Windows NT™ operating system. After the data were imported into the ERDAS file format, I rectified each band using ten ground control points. I used the cubic convolution routine in the software because this resampling method tends to enhance boundaries between contrasting cover types. To sharpen the image, the data were transformed using both haze reduction and edge enhancement algorithms. Noise reduction was also accomplished to highlight the contrasts between areas of different tone within the imagery. Finally, I used scientific visualization to test various band combinations to find which offered the best delineation between lithostratigraphic units. Scientific visualization is the graphical exploration of data to obtain understanding of existing patterns (Jensen, 1996).

Structure Contour Maps

I prepared structure contour maps for selected surface and subsurface contacts using Geographix Exploration System software (Geographix, Inc., 1996). Raw data collected from fieldwork and examination of assorted subsurface records were collated and entered into a three-dimensional database. I used nonlinear interpolation between data points that resulted in the simplest contour surface in the creation of these maps. I was required to add several ghost data points to the data set near the boundaries of the study area to force contour lines to reflect regional dip that exists in this part of Kansas.

I collected approximately twenty data points from exposures of the base of the Altamont Limestone. I derived elevation data for these points by locating the exposure on the appropriate topo sheet and recording the elevation as indicated on the map. I was able to acquire a few subsurface readings for this contact using some of the more reliable driller's logs on record at the Kansas Geological Survey. I used these data to prepare the structure contour map of the base of the Altamont Limestone.

I used subsurface data from the Kansas Geological Survey well log library to prepare a structure contour map of the top of the Mississippian Limestone. These data were mostly in the form of formation tops called on scout cards and completion reports as geophysical log coverage of the study area is incomplete. Additionally, I relied heavily on the map prepared by Blair and Berendsen (1992) as a guide in understanding the overall geometry of the study area and surrounding regions.

RESULTS

Geological Mapping

Identification of lithostratigraphic contacts for use in field and imagery-based mapping became the first challenge of the study. Several previous investigators, including Jewett (1945,1965), Zeller (1968) and Heckel (1991), had divided strata differently into distinct formations and members (fig. 8). The most recent reclassification (Heckel, 1991) introduced several units that are bounded by shale/shale contacts in the study area. Extensive development of soils and agriculture in this part of southeast Kansas prevented the accurate location of these contacts. The unconformity at the base of the Missourian Hepler Formation and the top of the Desmoinesian Lost Branch Formation is one such example. In this case, the presumed near shore shale of the Hepler is differentiated from the presumed more marine shale of the Lost Branch. Virtually all shale beds in the study area weather light brown, thus, differentiation between the two becomes quite challenging in the field. Additionally, several of the units, which are afforded formation status by Jewett, Zeller and Heckel, are too thin to be adequately mapped at the chosen scale. As a result, I chose to use limestone/shale contacts as the key lithostratigraphic markers during this work. These contacts are much better exposed and can be projected from one outcrop to the next. The selected contacts, however, do not necessarily correspond to major stratigraphic boundaries between named formations or groups.

In cases where the actual contacts between formations were not used, such as the Sniabar/Mound City, I used formation thickness from the Prong Creek core (Heckel, 1991) to assist in determining the topographic locations of these contacts. Several shale/shale contacts exist in the study area. Where no discernable contact could be found in outcrop, I once again used Heckel's interpretation of the Prong Creek core to estimate the location of contacts in the field.

The following contacts can be recognized and mapped in the study area and served as lithostratigraphic markers (fig. 9):

1. Base of the Pawnee Limestone (base of the Myrick Station Limestone Member) with the top of the Labette Shale. The traditional contact is between the Anna Shale Member (Pawnee) and the Labette Shale. This shale/shale contact is poorly exposed in the study area.
2. Top of the Pawnee Limestone (top of the Laberdie Limestone Member) with the base of the Bandera Shale.
3. Base of the Altamont Limestone (base of the Amoret Limestone Member) with the top of the Bandera Shale.
4. Base of the Lenapah Limestone (base of the Norfleet Limestone Member) with the top of the Nowata Shale.

5. Base of the Sniabar Limestone Member with the top of the Mound City Shale Member.

Once the base or top of a selected limestone was located, the contact could be traced with relative ease. Examination of the geologic map (map pocket) demonstrates that lithostratigraphic contacts are generally sub-parallel to topographic contour lines. This is expected in regions of relatively flat lying strata and agrees with earlier characterizations of the area as one in which flat lying strata dip gently to the west at the rate of about ten feet per mile (Heckel, 1991). Closer examination of these rocks reveals subtle folding present in the surface which will be discussed later.

Imagery-Based Geological Mapping

Prior to completion of the traditionally prepared geological map, I used satellite imagery in conjunction with a brief field survey to create a preliminary map. Initially this was intended as an aid in locating potentially useful outcrops. During preparation of the imagery-based map, however, I decided that a comparison of the two end products might prove to be informative. I prepared the LANDSAT TM data as described earlier. Upon completion, I selected band combinations which best differentiated between the exposed lithic units. Both true color and false color infrared images were too heavily dominated by vegetative patterns to shed much light on the rocks exposed at, or concealed slightly below the surface. After reviewing a magnitude of various band and color gun combinations, I discovered one that allowed easy recognition of two of the principal formations present (Hertha and Pawnee). This combination assigned Bands 5, 7 and 2 to

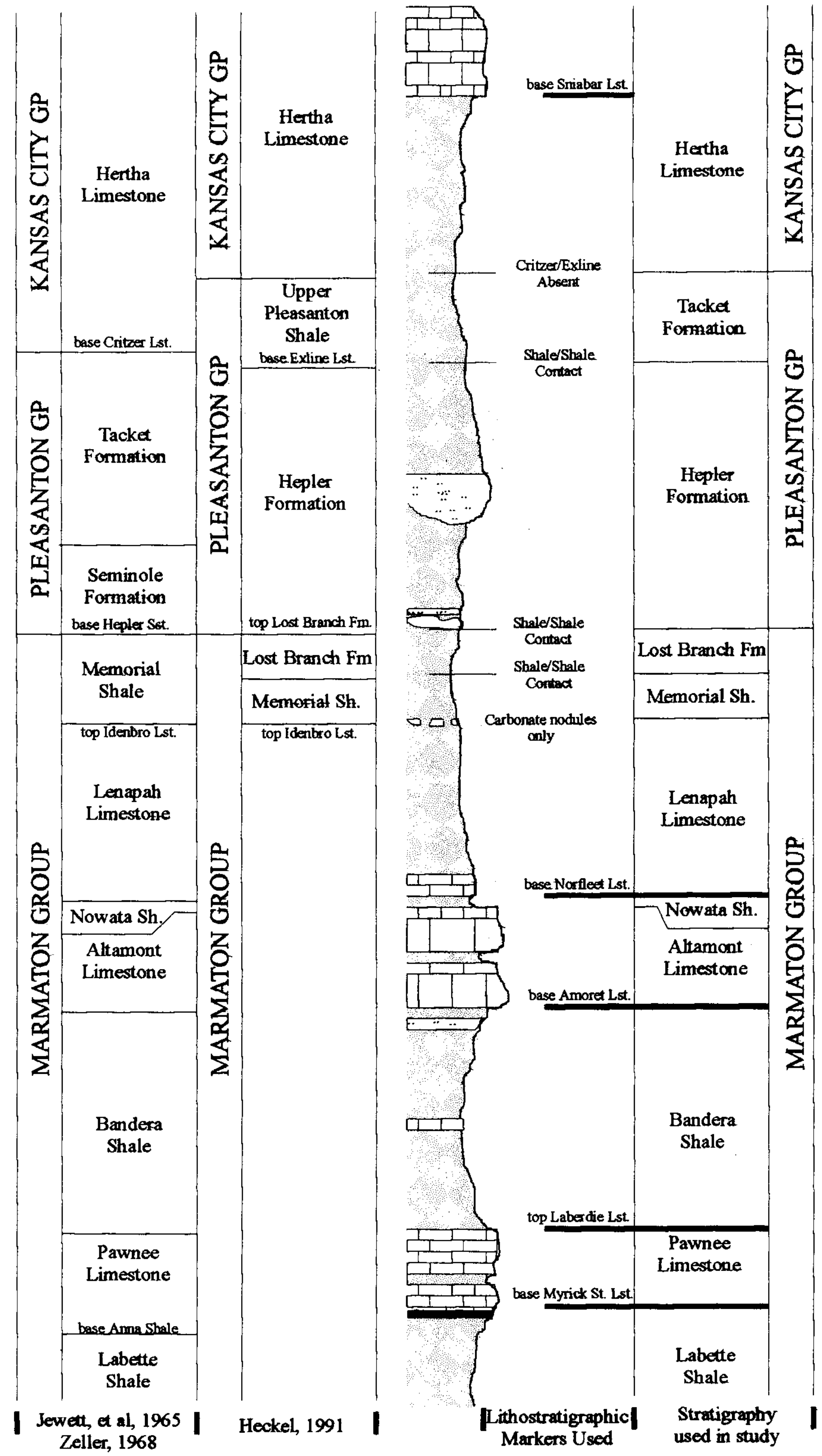


Figure 9. Summary of lithostratigraphic markers selected for use in mapping of the study area. Relative thickness of units is represented in the diagram (units modified from Zeller, 1968 and Heckel, 1991, West and Sawin, 1997).

the red, green and blue monitor color guns respectively. Bands 5 and 7 are both mid infrared, while band 2 corresponds to the green portion of the visible spectrum.

Examination of a wide view image (plate 1), that covers a region roughly four times the size of the study area, demonstrates the ease with which the Pawnee and Hertha Limestones can be distinguished from adjacent strata. In this image, both of these formations are yellow in color where they are exposed or very near the surface. The Hertha Limestone forms an escarpment that dominates the western quarter of the image. The Pawnee Limestone forms large, flat dip slope fields and escarpments along Pawnee Creek in the eastern third of the image. The yellow color is an indirect indicator of the limestone's presence. Much of the image's appearance is dependent upon vegetative cover. Clareson stony silty clay loam soil forms on much of the Hertha and Pawnee. This soil is characterized as stony and droughty, making it most suitable for range and generally unsuited for cultivated crops (USDASCS, 1973,1981). This, in turn, produces a reduced infrared signature resulting in a yellow hue. Because of this distinctive coloration, the contacts of these units are relatively easy to trace.

The Altamont Limestone, although a prominent ridge-forming unit, does not exhibit the same yellow color as the Pawnee and Hertha formations. It, in fact, appears purple, which makes it similar in appearance to much of the area underlain by shale. This is due to more highly developed soils that develop on much of the Altamont. Thicker soil horizons support more intense agricultural development and increase the infrared signature of this zone, resulting in a purple hue. Soil types developed on the Altamont are generally Catoosa silt loam or Kenoma silt loam of which two thirds or more are cultivat-

LANDSAT TM IMAGE
DECEMBER, 1986

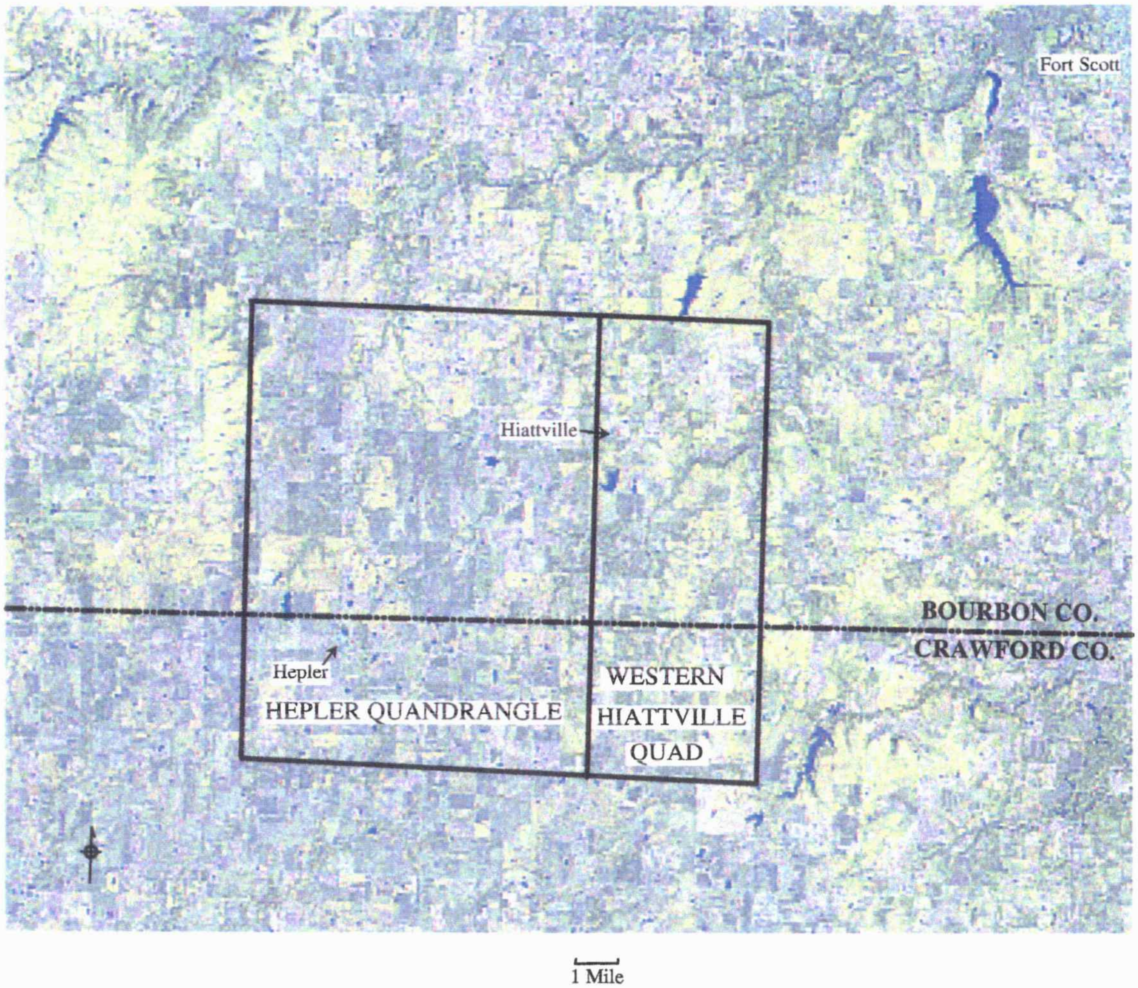


Plate 1. Wide view LANDSAT TM image (bands 5,7,2 = RGB) of the study area and surrounding regions. Note the prominent outcrop of the Hertha Limestone in the northwest part of the image. A similar pattern can be seen in the southwest where the Pawnee Limestone forms distinct bluffs. The Altamont Limestone outcrop in the central part of the image is much less distinct and purple in hue due to the more widespread development of agriculture. The area shown is approximately 30 miles wide by 25 miles high.

ed in Bourbon County (USDASCS, 1973,1981). This made tracing the Altamont/Bandera and Altamont/Lenapah contact impossible using imagery alone.

Increasing the image magnification to concentrate on the roughly 70 square miles of the study area created a new challenge. At this level of magnification individual pixels become visible increasing the grainy appearance of the image (plate 2). Major cultural and physical features are visible (plate 3) and may be used for reference purposes, but the previously clear contacts begin to blur. This level of magnification is required to study the small scale phenomena exposed in the study area, but the lower limit of resolution available in the LANDSAT TM sensors (30 X 30 meters, approx. 100 X 100 feet) prevents clear viewing at this scale.

The most difficult task in imagery-only based mapping came in distinguishing shale-dominated formations that occur between the top of the Altamont Limestone and the base of the Sniabar Limestone Member. The outcrop of the Pleasanton Group appears to correspond to a slightly darker purple region that roughly parallels the ridgeline formed by the Hertha Limestone in the west and extends toward the center of the study area in the vicinity of the town of Hepler. This trace is tenuous at best and drawing it involved more guesswork than fact. The Lost Branch Formation, Memorial Shale, Lenapah Limestone and Nowata Shale could not adequately be seen on the image and the top of the Lenapah Limestone was inferred based on the initial field survey.

The imagery-based geologic map of the study area (plate 4) therefore contains a large degree of uncertainty. Formations between the Pawnee Limestone and the Sniabar Limestone Member are not easily distinguished forcing several separate litho-stratigraphic units to be grouped together in an effort to increase the validity of the map.

**LANDSAT TM IMAGE
HEPLER AND HIATTVILLE
QUADRANGLES, DECEMBER, 1986**

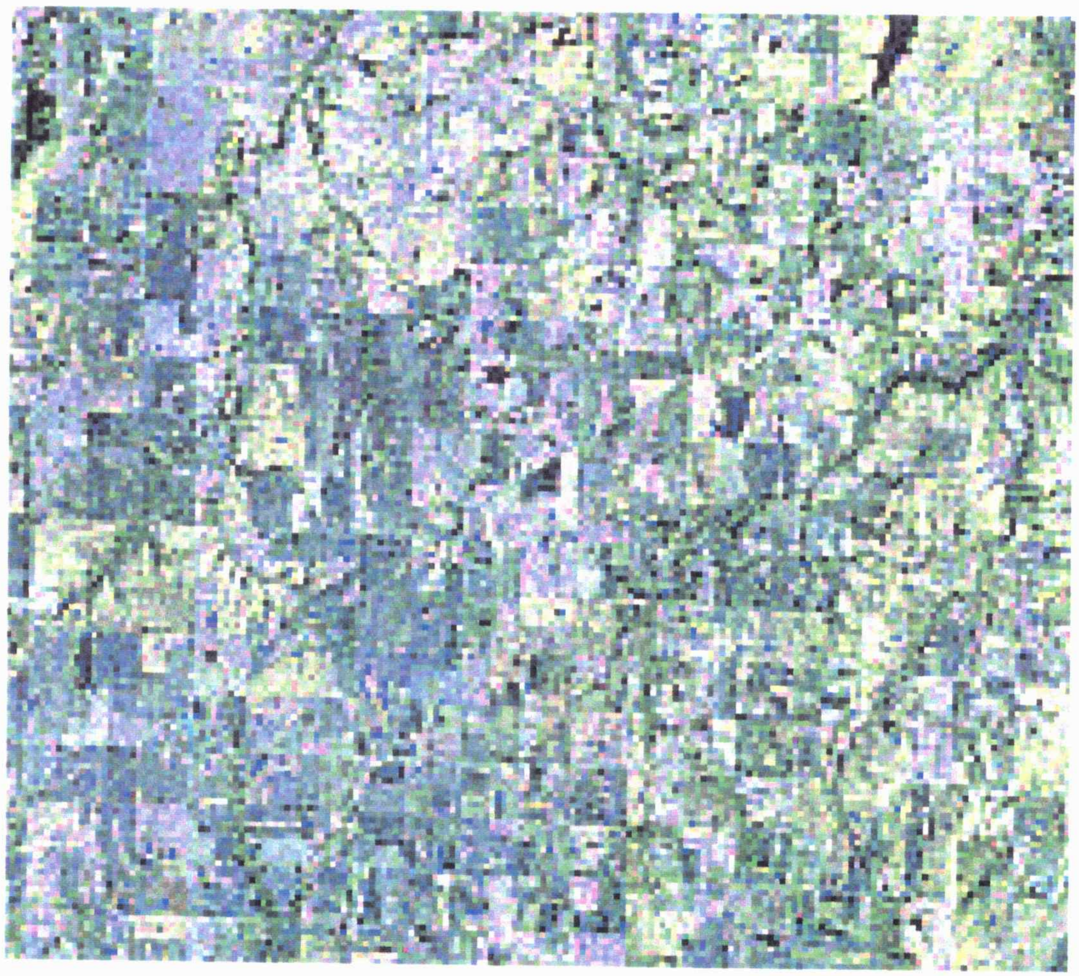
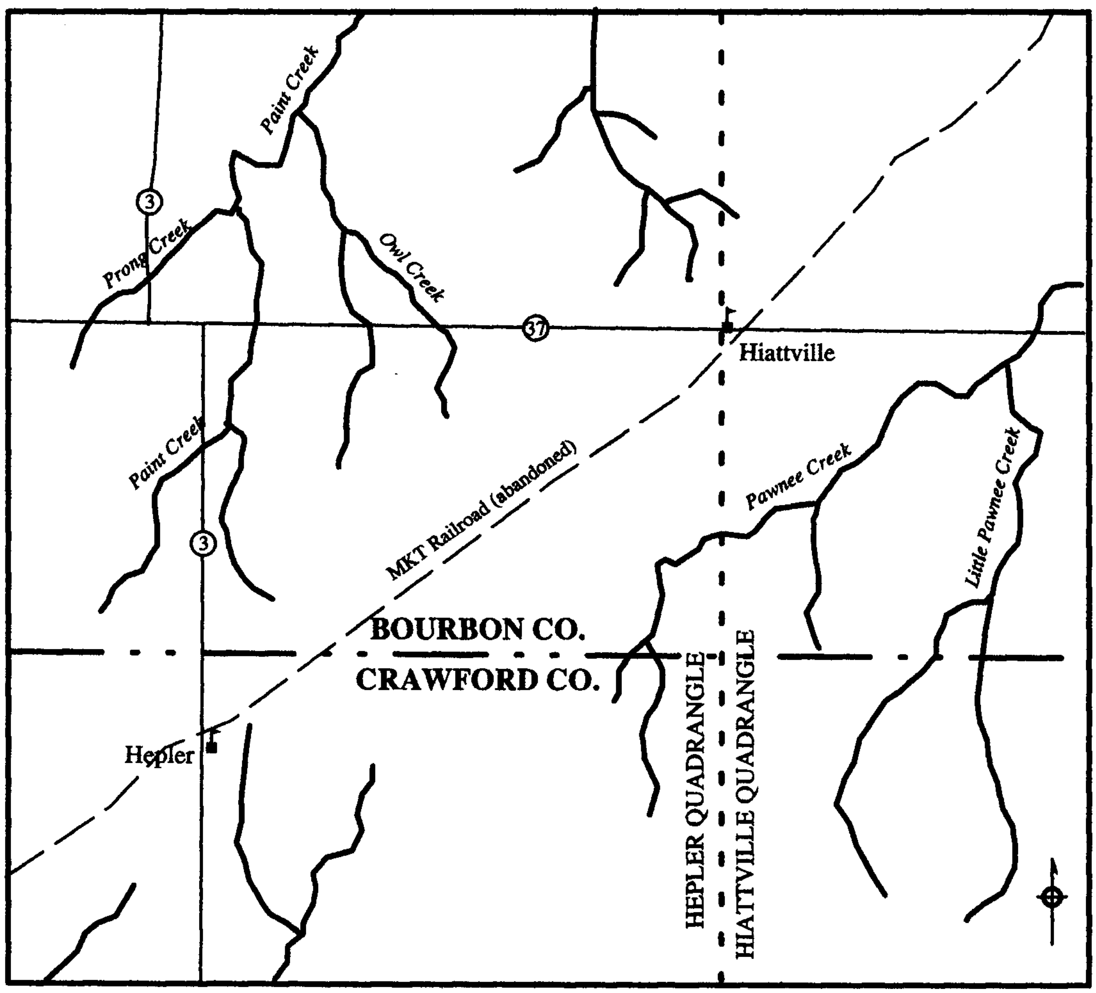


Plate 2. LANSAT TM image of the study area (bands 5,7,2 = RGB). As the magnification is increased many of the details seen on the wider view (Plate 1) are obscured as individual pixels become visible.

REFERENCE MAP: HEPLER AND HIATTVILLE QUADRANGLES, 1997

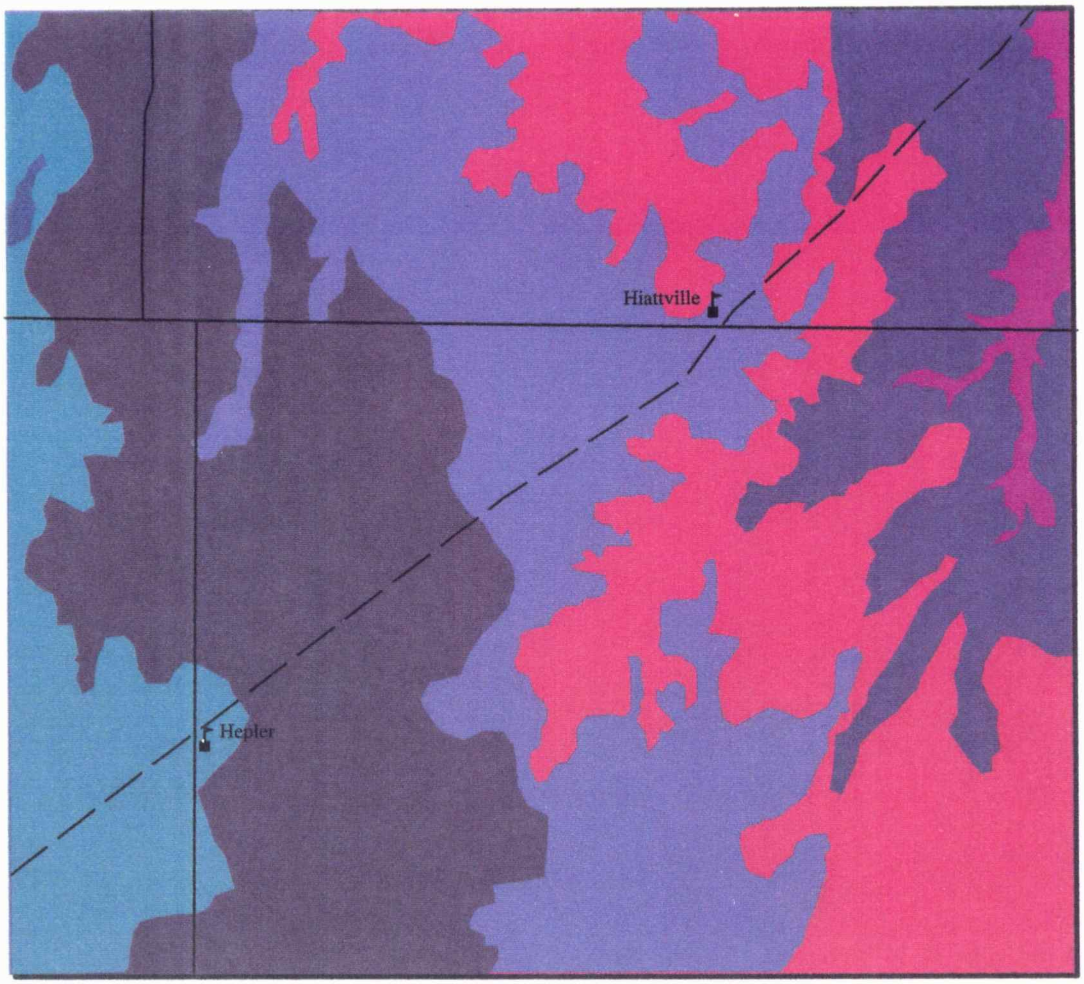


REFERENCE MAP SYMBOLS

Town

③ State Highway

Plate 3. Major natural and cultural features of the study area identified and traced from the LANDSAT TM image (Plate 2).



EXPLANATION OF AREAL GEOLOGY

PENNSYLVANIAN SYSTEM

MISSOURIAN SERIES

KANSAS CITY GROUP

Hertha Limestone

PLEASANTON GROUP

Tacket Formation and Hepler Formation

DESMOINESIAN SERIES

MARMATON GROUP

Lost Branch Formation, Memorial Shale and Lenapah Limestone

Altamont Limestone

Bandera Shale

Pawnee Limestone

Labette Shale

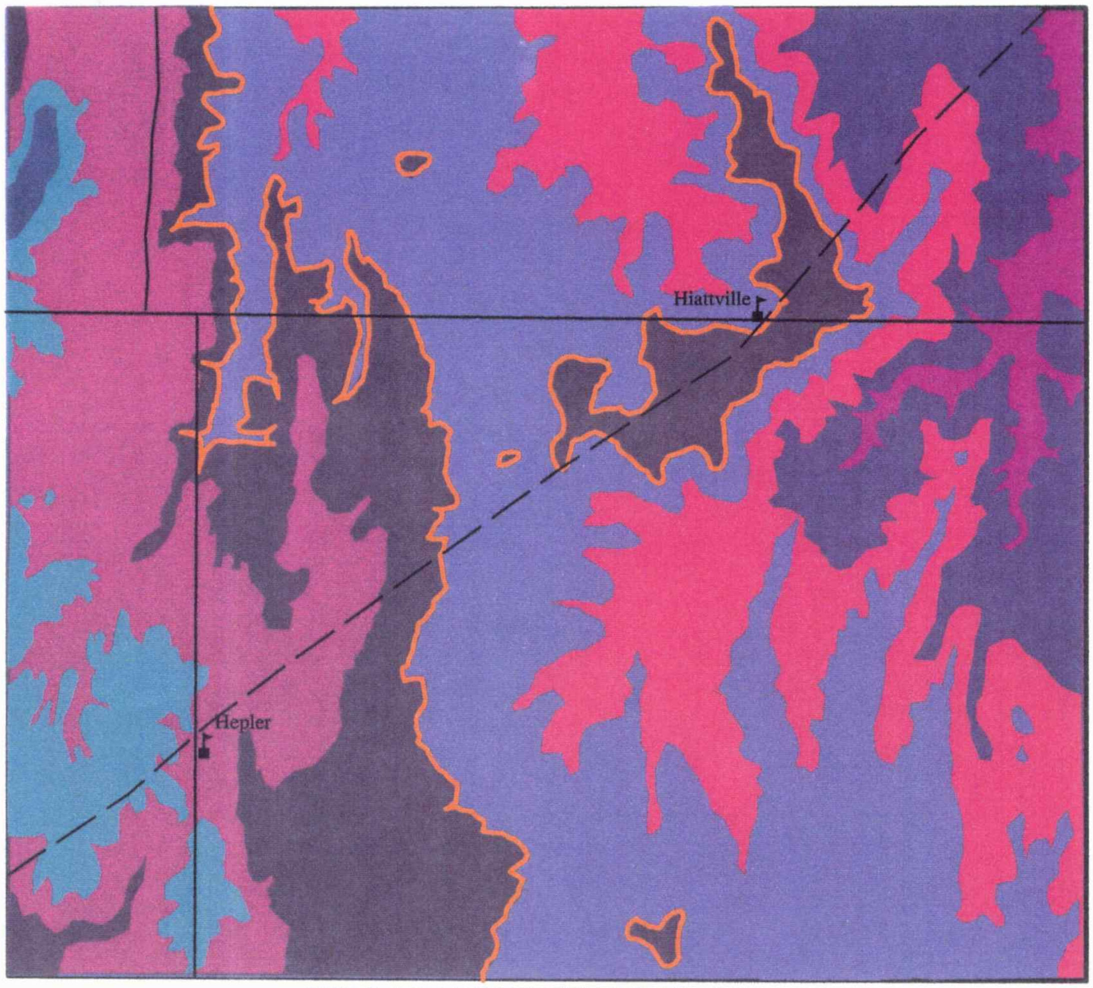
1 Mile

Plate 4. Geologic map of the study area based on interpretation of LANDSAT TM imagery and preliminary field reconnaissance. Note that several formations have been combined because they cannot be distinguished using imagery alone.

The units that can be distinguished with the highest degree of confidence are the Pawnee Limestone, Bandera Shale, Altamont Limestone and the Sniabar Limestone Member.

A comparison to the traditionally generated geologic map (plate 5) reveals the limitations of a solely imagery-based approach. Outcrop patterns are similar in overall appearance, but the accuracy with which contacts are located is low. The distinctive Sniabar Limestone Member and Pawnee Limestone outcrops are readily identified, but much of the strata in between are difficult to differentiate. Of particular note is the outcrop of the Lenapah Limestone in the vicinity of the town of Hiattville. This exposure is only known from field reconnaissance and was not discernable from the satellite imagery used. The Nowata Shale, which averages five feet in thickness, is also absent from the satellite views. Due to the difficulty in separating the Memorial Shale and the Lost Branch Formations these units are grouped together in the imagery-based map. This is also the case with the Hepler and Tacket Formations that are grouped together as the Pleasanton Group on the imagery-based map.

Imagery-based maps of this part of Kansas are useful tools, but have limitations based on several factors. The numerous thin members and formations that are subdivisions of the stratigraphic column are generally too thin to be visualized on LANDSAT TM imagery due to the lower limit of its spatial resolution. Heavy vegetation, thick soils, and extensive agricultural development all conceal bedrock from satellite observation and differentiation. These factors tend to restrict imagery use in southeast Kansas to the production of predictive maps as guides for field reconnaissance and study. Image interpretation is a useful compliment to field study, not a replacement.



EXPLANATION OF AREAL GEOLGY
PENNSYLVANIAN SYSTEM

MISSOURIAN SERIES

KANSAS CITY GROUP

- Hertha Limestone

PLEASANTON GROUP

- Tacket Formation and Hepler Formation

DESMOINESIAN SERIES

MARMATON GROUP

- Lost Branch Formation and Memorial Shale
- Lenapah Limestone
- Nowata Shale
- Altamont Limestone
- Bandera Shale
- Pawnee Limestone
- Labette Shale

1 Mile

Plate 5. Geologic map of the study area based on thorough field reconnaissance. Besides changes in the lithostratigraphic outcrop pattern, several additional units can be identified in the field that are not visible on imagery used.

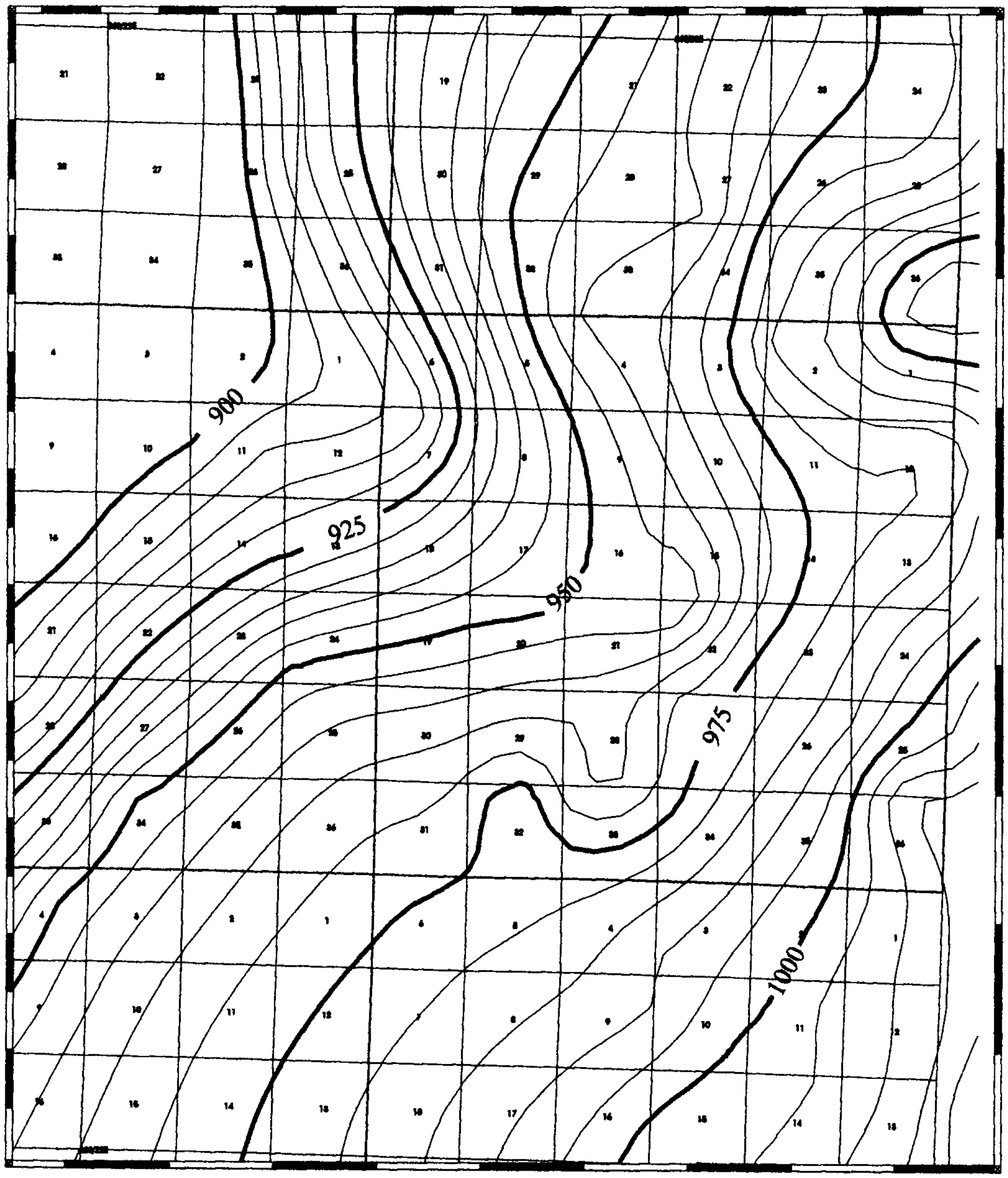
Structural Trends

The base of the Altamont Limestone (Amoret Limestone Member) was the most widely exposed reliable contact. A structure contour map of this contact (fig. 10) indicates that it is a gently warped surface dipping gently to the WNW at approximately 15 feet per mile. A shallow trough extends from Section 1, T.27S., R.22E. to the center of T.27S., R.22E., its axis striking N50W and plunging slightly to the northwest. From this point, it splits into two shallow arms, one extending into the northwest part of T.27S., R.22E., the other branching south and terminating in Section 30, T.27S., R.22E. Dip of this surface is steeper in the northwest part of the study area.

The divide between the Marmaton and Neosho River drainage basins winds through the southern third of the study area. Although the Altamont Limestone does not demonstrate significant relief, it does appear to influence the actual location of the divide. The low-relief structural ridge that extends into Section 32, T.27S., R.23E. coincides precisely with the divide, suggesting that this mild fold, that forms the southern edge of the trough, is substantial enough to influence the surface drainage pattern.

During field reconnaissance, I discovered two small, compressional folds that deform the Lenapah Limestone exposed along the bank of Prong Creek at outcrop HE-51 (appendix A) in Section 10, T.27S., R.22E. The axial planes of these folds strike N20W (fig. 11). These folds are sub-parallel to the Pittsburg Tectonic Zone (Blair and Berendsen, 1992) and are located on the eastern edge of this zone as it crosses the study area. The folds are about 500 feet apart and are very similar in appearance. Strata deformed in the folds return to regional dip less than 30 feet from the each axis. Close examination of the rocks indicate that this deformation occurred after lithification,

STRUCTURE MAP
BASE OF THE ALTAMONT LIMESTONE



Contour Interval = 5 Feet

Figure 10. Structure contour map of the base of the Altamont Limestone.

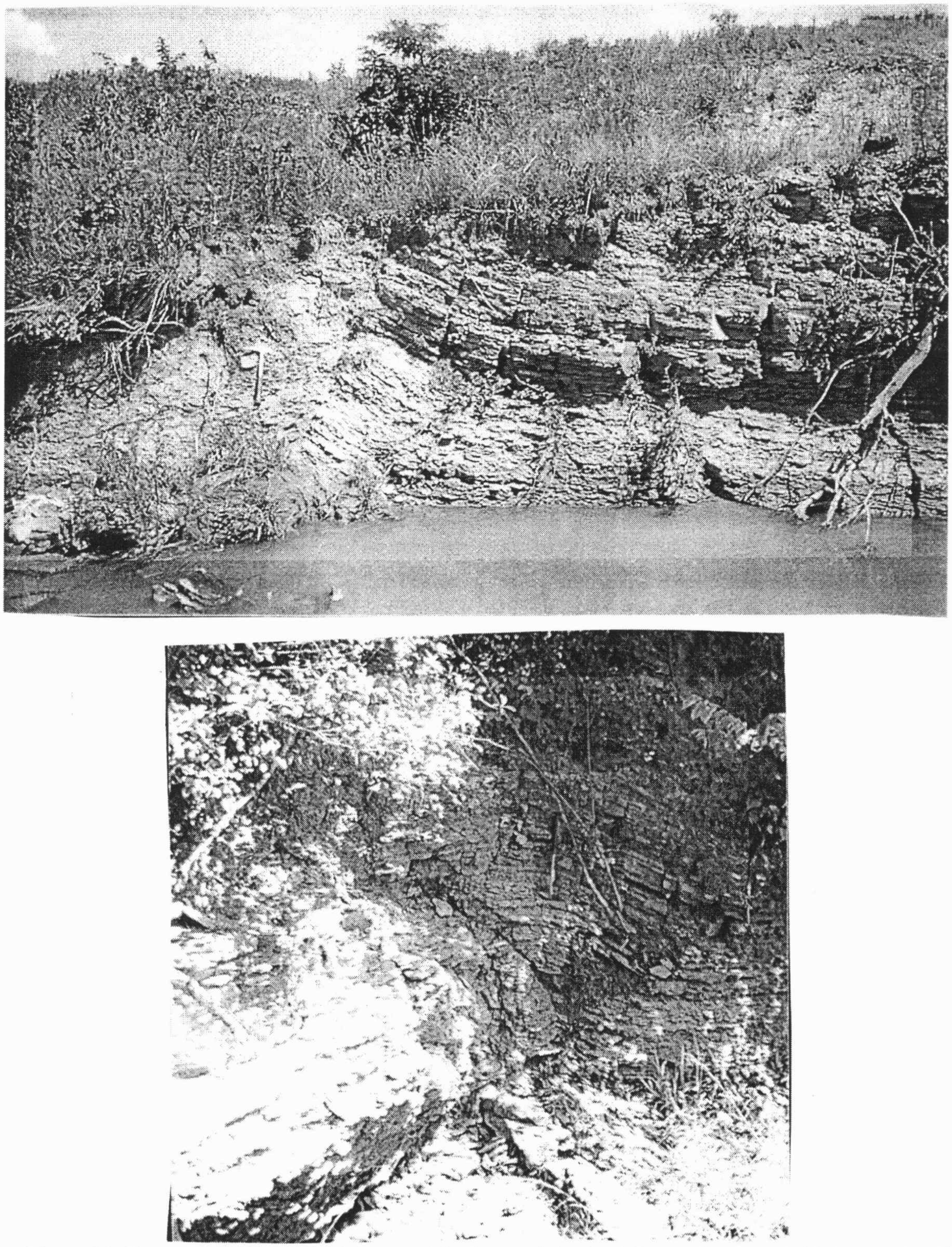


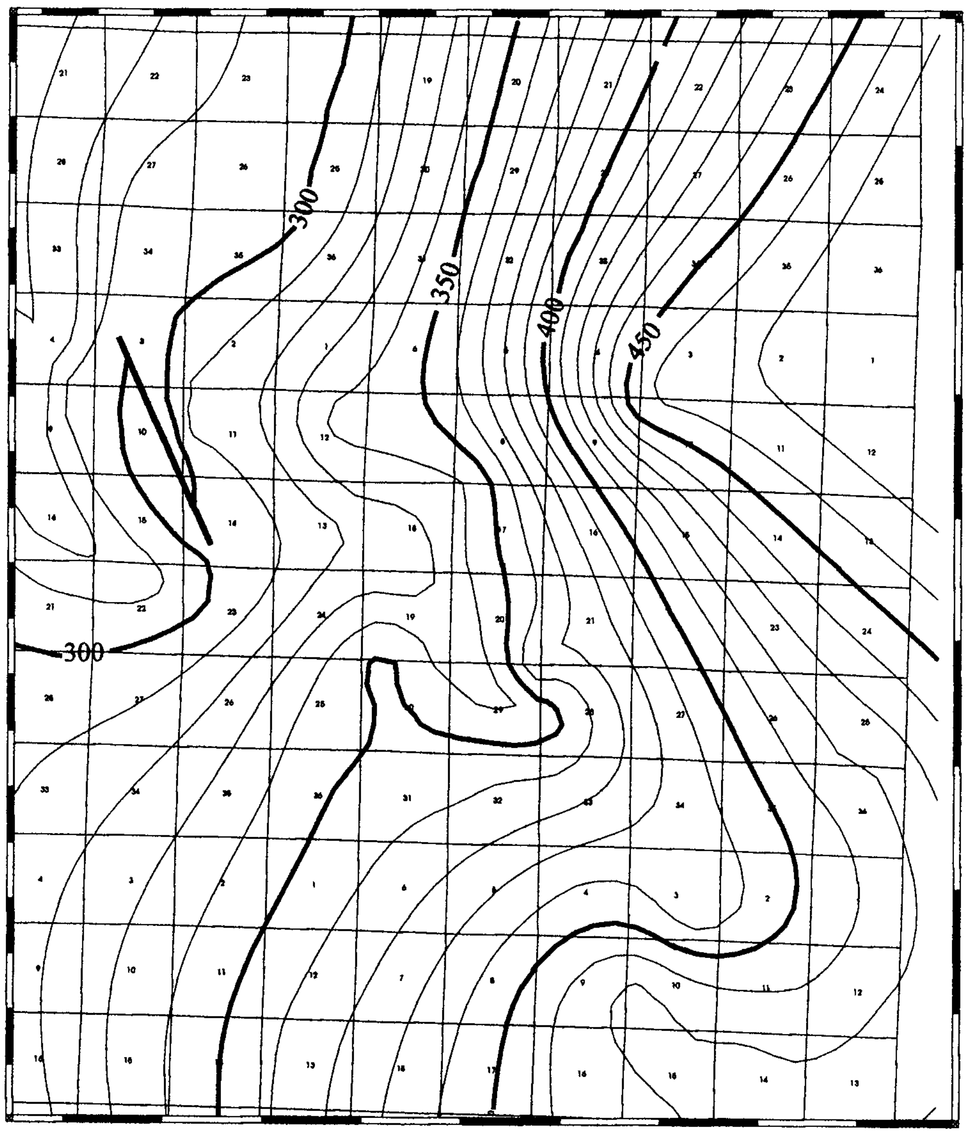
Figure 11. Photographs of two folds exposed in the south bank of Prong Creek at field site HE-51. The limestone at the bottom of the exposure is the Norfleet Limestone Member of the Lenapah Limestone with the Perry Farm Shale Member above.

making the folds post-Desmoinesian in age, potentially linking the development of these features to the general time frame of the Ouachita Orogeny and the related formation of the Central Kansas and Nemaha Uplifts.

Many oil and gas exploration wells penetrate the top of the Mississippian Limestone, approximately 750 feet below the surface, in and around the study area. This surface has previously been used (Blair and Berendsen, 1992) to examine regional subsurface structural trends in southeast Kansas. I selected the Pennsylvanian/Mississippian contact as the datum for the preparation of the subsurface structure contour map (fig. 12). The Mississippian Limestone dips gently to the WNW at approximately 20 feet per mile. Blair and Berendsen (1992) identified a fault in Sections 3, 10, 11 and 14, T.27.S., R.22E. striking N18W. Since wells near this feature fail to penetrate the fault plane, it is impossible to classify it as normal or reverse. The Mississippian Limestone is gently folded with a distinct trough running diagonally through the center of the study area. This fold extends from Section 12, T.28S., R.23E. northwest into Section 10, T.27S., R22E with an axial bearing of N35W and a slight plunge to the northwest. This syncline is bounded by two ridges, the more dominant of which is to the south. The crest of this anticline, although of low relief, extends from Section 15, T.28S. to Section 30, T.27S.,R.22E.

The base of the Altamont and the top of the Mississippian Limestone are separated by over 750 feet of Pennsylvanian strata, primarily shale. Several unconformities are thought to exist in this interval. Additionally, the intervening units are known to vary in thickness laterally. Despite these facts, the structure contour maps of these two surfaces are markedly similar. Both dip gently to the WNW, the Mississippian

STRUCTURE MAP
TOP OF THE MISSISSIPPIAN LIMESTONE



Contour Interval =10 Feet

Figure 12. Structure contour map of the top of the Mississippian Limestone.

somewhat more steeply. Both horizons exhibit a gently folded, shallow trough or syncline cutting across the center of the study area. Both contain gentle anticlinal folds bounding the trough, the more pronounced lying to the south. The axes of all of these folds are sub-parallel to each other and the Pittsburg Tectonic Zone. The Marmaton/Neosho river basins divide occurs atop a structural ridge visible in both horizons.

The fault identified on the subsurface map is not exposed on the surface. The folds exposed along Prong Creek are surface evidence of deformation that affected the northwest part of the study area. These folds are located less than a half mile west of the subsurface fault on the upthrown block. These compressional structures could have been coeval and thus the fault may have been reverse. This cannot be positively ascertained as none of the nearby wells penetrate the fault plane. Therefore, the dip of the fault plane is unknown. Both the fold axes and the fault plane are sub-parallel to the Pittsburg Tectonic Zone. Faults studied in adjoining tectonic zones have normally shown more lateral than vertical displacement (Blair and Berendsen, 1992). These faults are thought to represent the brittle fracturing of the thin Paleozoic sedimentary cover resulting from reactivation of basement faults during the Ouachita Orogeny in late Pennsylvanian and early Permian time.

The fact that the general geometry of the Mississippian and Altamont structures are so similar, suggests that these features developed after lithification of Desmoinesian strata, which is further supported by the folds along Prong Creek. Had deformation occurred earlier, post-Mississippian sedimentation would easily have masked such subtle structures. Had deformation occurred post-deposition/pre-lithification, it is likely that differential compaction of the shale dominated formations would also have eliminated the signature of earlier developed structures.

CONCLUSION

The most significant outcome of this study was the production of a detailed geologic map of the study area (map pocket). This work has assisted the effort to complete geologic maps for all of Kansas and has provided data for an area in which no public record existed.

Detailed mapping of the study area reinforces the suggestion that surface features reflect identified regional scale structural trends in the subsurface. Surface structures present in this part of Kansas are so subtle that only detailed study and mapping may identify them. The most useful tools for identifying these features are highly detailed geologic maps and structure contour maps of formations exposed at the surface and at depth. These maps must be prepared with careful attention to detail or gentle folds and faults may be overlooked. Once identified, surface structures may be compared to previously defined regional structural trends.

In this part of the state, accurate 1:24,000 scale geologic maps may only be produced utilizing a traditional field mapping approach. Satellite imagery interpretation, although useful for regional perspective comparisons and trend identification, is not capable of identifying the small-scale features present. Current image resolution restrictions (30 meters) limit the size of observable phenomena to a scale that is inadequate for the visualization of the subtle structures exposed on the surface. Because of current resolution restrictions, exsisting satellite technology is inferior to aerial photography in the search for subtle structures and small outcrops. This is changing, however, as more sensitive instruments will soon be in orbit. Currently, LANDSAT image interpretation should be used with caution to obtain a general sense of the geologic setting in this region.

GPS technology, on the other hand, proved an invaluable aid in field work. Many of the best exposures were found in winding, densely vegetated stream beds. Determination of the location of such sites can be highly inaccurate without use of a GPS unit. The elevation data provided, however, was inaccurate. Errors in elevation commonly exceeded +/- 200 feet. Thus, elevation data for each exposure is limited by the accuracy of the topographic map on which the site is plotted.

To better understand the relationship between subtle surface structures and the deeper structural fabric, future work should include further detailed mapping of adjoining quadrangles. Additionally, further research into the kinematics and timing of deformation may shed valuable insight on the local accumulation of hydrocarbons. These topics are only briefly touched on in this work, if at all, and will require considerable investigation to understand fully. The link between surface features and deeper structures is clearly evident in this study and suggests that detailed examination of surface phenomena utilizing traditional field methods may indeed provide valuable insight into the complex, poorly understood subsurface.

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APPENDIX A
FIELD SITE DESCRIPTIONS

EXPLANATION:

Site numbers represent field locations of note documented during the course of field reconnaissance in the Hepler (HE) and Hiattville (HI) Quadrangles. Sites are grouped according to township and range and listed in section sequence order.

Location is intended to give a general position for each site. Exact locations can be found on the 1:24.000 reference map (map pocket) accompanying this work.

Descriptions summarize the strata exposed at each site. These notes are presented in an abbreviated form with emphasis on lithostratigraphic information and elevations for marker horizons when appropriate.

HEPLER QUADRANGLE

T.26S., R.22E.

SITE :	SEC:	LOCATION:	DESCRIPTION:
HE1	25	SW/SW/SE/SW	Upper Bandera Shale, 5 ft., brown, very fine grained sandstone in road ditch.
HE2	25	SW/SE/SW/SE	Upper Bandera Shale, 4-½ ft., brown, very fine grained sandstone, north side of road.
HE3	27	C, south line	Possible Hepler Sandstone Member, 2 ft., light brown, very fine grained sandstone, crosses road.
HE4	27	¼ mi. north of C, south line	Possible Hepler Sandstone Member, light brown, very fine grained sandstone.
HE5	28	SE corner	Possible Memorial Shale, light gray shale with limestone float in streambed, south side of road.
HE6	34	SW ¼	Possible Mound City Shale, light gray fissile shale exposed on hill slope in erosion scar.
HE7	34	SW ¼	Light brown calcareous concretions scattered on soil surface.
HE8	34	SW ¼	Light brown shale with orange brown very fine grained sandstone in creek bed, possibly Hepler Sandstone Member.

T.26S., R.22E. (continued)

SITE :	SEC:	LOCATION:	DESCRIPTION:
HE9	34	SW ¼	Hepler Formation, light brown shale with 3 ½ ft. light brown sandstone.
HE10	34	SW ¼	Light brown calcareous concretions scattered on ground.
HE11	35	SE ¼	Altamont Limestone, probably Worland and Amoret Limestone Members, exposed on east side of Paint Creek in large slump blocks forming cliffs approximately 15 ft. tall. Limestone extends approximately 10 ft. further up the bank, partially covered with soil. Lake Neosho Shale Member not visible.
HE12	35	SE ¼	Altamont Limestone, unknown interval, forms creek bed.
HE13	35	SE ¼	Perry Farm Shale Member, light brown sandy shale with well developed upper sandstone member: very fine grained, slightly micaceous, on hillside, north side of trail.
HE14	35	SE ¼	Altamont Limestone, probably Worland Limestone Member. Very large exposure, forming banks and stepped bed of creek. Limestone is weathered very light gray; top surface with a distinctive nodular weathered texture. Contains fossil brachiopods and crinoids, though not highly fossiliferous. Total thickness estimated at 12 ft.
HE15	35	SW ¼, south line	Perry Farm Shale Member. Light gray, thinly laminated shale 4 ft. thick, with 2 ft. very fine grained, red-brown sandstone.
HE16	35	SW ¼, south line	Perry Farm Shale Member, similar to HE15.
HE17	36	NE ¼, north line	Base Altamont Limestone (Amoret Lst. Mbr.) 910 ft. ASL.

T.26S., R.23E.

SITE:	SEC:	LOCATION:	DESCRIPTION:
HE18	27	SW ¼, south line	Base Altamont Limestone (Amoret Lst. Mbr.) 950 ft. ASL.

T.26S., R.23E. (continued)

SITE:	SEC:	LOCATION:	DESCRIPTION:
HE19	27	SW ¼, south line	Base Altamont Limestone (Amoret Lst. Mbr.) 950 ft. ASL.
HE20	28	SW/SE/SE/SE	Altamont Limestone, unknown member crossing road.
HE21	28	SW/SW/SE/SE	Upper Bandera Shale; brown, very fine grained sandstone in south side road ditch.
HE22	28	SE/SW/SW/SW	Bandera Shale.
HE23	29	SE/SE/SW/SW	Upper Bandera Shale; brown, very fine grained sandstone in contact with large slump block of gray, fossiliferous basal Altamont (Amoret Lst. Mbr.).
HE24	30	South line, W of C,	Upper Altamont (possibly Worland) Limestone; highly fossiliferous, gray limestone, 3-½ ft thick. Exposure parallels road on each side for approximately 250 ft.
HE25	30	SW ¼, south line	Altamont Limestone, light gray, 2 to 3 ft. thick, crosses road.
HE26	31	NE/SW	Altamont Limestone, light gray, slightly shaly, 2 to 3 ft. exposed in creek bed.
HE27	32	Near C, south line	Altamont Limestone, thin, light gray, fossiliferous, crossing road from north to south.
HE28	33	SE ¼, south line	Upper Bandera Shale, brown sandstone in creek bed.
HE29	33	SE ¼, east line	Bandera Shale, unknown portion.
HE30	33	NE ¼, east line	Altamont Limestone, crossing road.
HE31	34	SW ¼, west line	Base Altamont Limestone (Amoret Lst. Mbr.) 950 ft. ASL.
HE32	34	SE/SW/SW/SW	Possible base Altamont Limestone, 945 ft. ASL.
HE33	34	C, south line	Altamont Limestone, near base, contact not seen.

T.27S., R.22E.

SITE:	SEC:	LOCATION:	DESCRIPTION:
HE34	1	SW/SE/SE/SE	Contact of Lenapah Limestone (Norfleet Lst. Mbr.) with Nowata Shale, in road cut, south side of road.
HE35	2	NE ¼	Altamont Limestone, near top (Worland), 3 to 4 ft. exposed in Paint Creek bed and bank, gray, slightly fossiliferous.
HE36	2	NE ¼	Upper Altamont Limestone; long exposure along Paint Creek bed, gray, fossiliferous limestone with distinctive "microkarst" weathered upper surface forming nodules and knobs.
HE37	2	SE ¼	Altamont Limestone; long exposure in Paint Creek bed, similar to HE36.
HE38	2	SE ¼	Altamont Limestone forming bed of Paint Creek.
HE39	2	SE/SE/SE	Altamont Limestone forming bed of Paint Creek; long exposure extending north and south of Highway 39 bridge; gray limestone with limited fossils.
HE40	2	NE/NW/NE	Lenapah Limestone/Nowata Shale contact. Norfleet Limestone Mbr. (Lenapah): 2-ft. gray, fossiliferous limestone forming ledge above Prong Creek, base at 895 ft. ASL. Nowata Shale: 3 ft. light brown, sandy shale extending to water surface (photo).
HE40A	2	NW/NE/NE (west bank Paint Creek)	Altamont Limestone (Worland): 5 ft, gray, massive, extending to water level and forming creek bed. Nowata Shale: in contact with top of Altamont, 2 ft. exposed, 5 ft. covered, light brown fissile shale with red-brown, very fine grained sandstone lenses (2 to 4 in.). Lenapah Limestone (Norfleet Lst. Mbr.): exposed in copse of pine trees, 2-½ ft., gray limestone approximately 2/3 of the way to the hill crest.
HE41	2	NE/NW	Lenapah Limestone (Norfleet Lst. Mbr.): 2-½ ft. light gray limestone (dark gray, sparry on fresh surfaces) forming bed of Prong Creek, 900 ft. ASL.

T.27S., R.22E. (continued)

SITE:	SEC:	LOCATION:	DESCRIPTION:
HE42	2	Near C, W/2	Perry Farm Shale, long exposure along south Prong Creek bank; 6 ft. light greenish gray, fissile shale with distinct orange staining, light brown to gray on fresh surfaces, contains silty to very fine grained quartz sandstone with minor amount of mica flakes, extensive ripple marks and some scour marks.
HE43	3	SE/NE/SE	Perry Farm Shale, 4-ft. exposure forms east bank of Prong Creek, gray fissile shale, dips to NNW truncating in a conspicuous joint.
HE44 sandy	3	SW/SE	Perry Farm Shale, light gray, fissile and brown, shale along Prong Creek banks, thickness varies from 2 to 5 ft.
HE45	3	NW/SW/SW/NW	Hepler Formation: brown sandy shale with minor amount brown, very fine grained sandstone.
HE46	3	Near C, NE ¼, north line	6 ft. thin bedded, light brown, sandy shale and siltstone or very fine grained sandstone, ripple marks, possibly Memorial Shale.
HE47	4	SE/NE/SE	5 ft. gray fissile shale overlain by 18 in. brown sandy shale, truncated by very fine grained, brown sandstone at top. Exposure follows creek bed east to west. Possibly near the base of the Hepler Formation.
HE48	4	E ½, SE/SE	Hepler Formation; waterfall ledge formed by 2-3 ft. brown, very fine-grained sandstone, hollow beneath ledge is 8-ft. gray, laminated shale/siltstone. Banks of pond ringed by same brown sandstone; Possibly the Lost Branch Formation/Hepler Formation contact.
HE49	4	SE corner	NW corner of road intersection; Heckel (1991) identifies the 2 ft. brown, very fine-grained sandstone as Hepler Sandstone; 3 ft. brown sandy shale exposed beneath.

T.27S., R.22E. (continued)

SITE:	SEC:	LOCATION:	DESCRIPTION:
HE50	10	NE/NW/NW/NW	Hepler Formation; light brown, very fine grained sandstone forms caprock for a long ridge that is an intermediate step between the Hertha Limestone ridgeline to the west and the valley to the east.
HE51	10	C, NE/NW	Lenapah Limestone: Norfleet Lst. Mbr. Forms Prong Creek bed; Perry Farm Shale exposed in bank, 2 ft. gray fissile shale at base, 10 ft. light brown sandy shale above. Tight compressional fold exposed in cut bank. Photographs and measurements from this exposure discussed in text.
HE 52	11	NE ¼	Altamont Limestone: 2 to 3 ft. gray, fossiliferous exposed in east bank of Paint Creek.
HE53	11	NE ¼, near C, east line	Altamont Limestone, 6 ft., forming Paint Creek bed and part of the east bank; limestone boulders exposed through soil along ledge outside creek.
HE54	11	NE/SE/NE	Altamont Limestone, light gray to white, fossiliferous, forming Paint Creek bed; large amount of limestone cobbles in creek bed.
HE55	11	S ½, SE/NE	Altamont Limestone along base Paint Creek.
HE56	11	NE/SE/NE	Altamont Limestone, 5 ft., light gray, fossiliferous.
HE57	11	NE/SE/SE	Base of Lenapah Limestone (Norfleet Lst. Mbr.) forms ledge on hillside in stand of pine trees, 2 ft, dark gray limestone, base covered, 940 ft. ASL.
HE58	11	NE/NE/SE/SE	Lenapah Limestone (Perry Farm Shale Mbr.), light brown, sandy soil with brown, very fine-grained sandstone float on the surface.
HE59	12	NW/SW/SW	Thin, gray limestone, probably Norfleet Lst. Mbr., 940 ft. ASL.
HE60	12	W ½,SW/SW	Perry Farm Shale, light brown, sandy shale exposed on hillside with brown, very fine-grained sandstone float littering the surface.
HE61	14	SE corner	Brown, sandy shale in road ditch; prob. Perry Farm Shale.

T.27S., R.22E. (continued)

SITE:	SEC:	LOCATION:	DESCRIPTION:
HE62	14	SE ¼, near C, south	Light gray shale overlying 1 ft. light gray limestone bed in line road ditch near creek bed, possible base of Lenapah Limestone, 940 ft. ASL.
HE63	14	Near C	Originally identified as the type section for the Hepler Sandstone (Jewett, 1945), exposure is actually Perry Farm Shale Member of the Lenapah Limestone. Exposure is badly deteriorated, but Norfleet Limestone Member is clearly visible at the water's edge along Paint Creek (Heckel, 1991).
HE64	22	SW/SE/SE/SE	Light brown, sandy shale with minor amount of very fine grained, brown sandstone (prob. Hepler Formation).
HE65	23	NE/NE	Base of the Lenapah Limestone. 4-½ ft. exposure: base is1 ft. gray limestone (Norfleet Lst. Mbr- 950 ft. ASL); middle, 2 ½ ft. (gray shale) and top, 1 ft. (light brown shale) are Perry Farm Shale Member.
HE66	24	Near NE corner	Memorial Shale. Thinly laminated, brown, sandy, fissile shale.
HE67	25	NE/NW	Brown sandstone exposed on south side of abandoned railroad right of way (prob. Memorial Shale).
HE68	28	SE/NE/NE	Curious isolated hill, standing well above surrounding terrain. Large amount of brown, very fine-grained sandstone float observed, but no outcrop; probable Hepler Sandstone Member.
HE69	34	South line, SW ¼	Hepler Sandstone Member crossing road north to south, 970 ft. ASL.
HE70	34	South line, SW ¼	Hepler Sandstone Member crossing road north to south, 970 ft. ASL.
HE71	34	South line, SW ¼	Hepler Sandstone Member crossing road north to south, 970 ft. ASL.

T.27S., R.22E. (continued)

SITE:	SEC:	LOCATION:	DESCRIPTION:
HE72	36	Near C, south line	Orange-brown sandstone in north side road ditch, prob. Perry Farm Shale Member.

T.27S., R.23E.

SITE:	SEC:	LOCATION:	DESCRIPTION:
HE73	4	NW ¼, north line	Bandera Shale, upper sandstone, south side of road.
HE74	4	NW ¼, west line	Base Altamont Limestone (Amoret); 960 ft. ASL.
HE74A	4	SE ¼, east line	Base Altamont Limestone (Amoret); 950 ft. ASL.
HE75	5	NW/NE/NE/NE	Altamont Limestone; limestone float on ground surface.
HE76	5	SW ¼, west line	Altamont Limestone; thin exposure, both sides of road in creek bed.
HE77	7	NW/NE/NW/NE	Base Lenapah Limestone (Norfleet Lst. Mbr.) 955 ft. ASL, south side of road, identified by Heckel (1991).
HE78	8	Near SW corner	Brown sandstone exposed south side of road, prob. Perry Farm shale.
HE79	8	SW/SE	Lenapah Limestone (Perry Farm shale), light brown sandy shale and sandstone exposed on hillside.
HE80	9	Near SW corner	Altamont Limestone; light gray limestone float exposed on surface.
HE81	9	SE ¼, east line	Top Altamont Limestone (Worland), light gray, fossiliferous with white nodules, 960 ft. ASL.
HE82	10	NW ¼, north line	Slabs of light brown, very fine grained, sandstone exposed in base of drainage ditch, south side of road across from cemetery entrance. Possibly Nowata Shale or Lenapah Limestone (Perry Farm Shale Member).
HE83	15	NW corner	Upper Bandera Shale sandstone bed; brown, very fine grained, 955 ft. ASL.
HE84	16	NW/SW/SW/SW	Bandera Shale/Altamont Limestone contact obscured by limestone float.

T.27S., R.23E. continued)

SITE:	SEC:	LOCATION:	DESCRIPTION:
HE85	16	SE/SE	Base Altamont Limestone (Amoret), 952 ft. ASL.
HE86	20	SE ¼, east line	Altamont Limestone, unknown section, crossing road east to west.
HE87	21	SW ¼, west line	Bandera Shale, exposure in creek bed, both sides of road.
HE88	21	SW corner	Altamont Limestone, near base, 973 ft. ASL.
HE89	21	NW/NE/NE/NE	Bandera Shale, upper sandstone bed, exposed in creek bed.
HE90	22	NW/NW, north line	Bandera Shale, upper sandstone bed, east side of road cut, 948 ft. ASL.
HE91	22	NW/NE, north line	Base Altamont Limestone (Amoret Lst. Mbr.) 950 ft. ASL.
HE92	22	SE/NW/NW	Bandera Shale, upper sandstone bed, 948 ft. ASL.
HE93	22	NW/SE/NW	Base Altamont Limestone (Amoret Lst. Mbr.) 963 ft. ASL.
HE94	27	NW/NE/NW/NW	Base Altamont Limestone (Amoret Lst. Mbr.) 970 ft. ASL.
HE95	28	C, west line	Altamont Limestone exposed in roadbed.
HE96	28	SE/SW/SE	Upper Bandera Shale; very good exposure along east bank of creek, north of the road. Light brown siltstone and shale, thinly laminated with ripple marks. Red-brown cross-bedded sandstone, 4 to 5 feet thick. Large slump blocks of Altamont Limestone (Amoret) resting on Bandera Shale near the east side of bridge.
HE97	28	Near C, south line	Base Altamont Limestone (Amoret Lst. Mbr.) 960 ft. ASL.

T.27S., R.22E. (continued)

SITE:	SEC:	LOCATION:	DESCRIPTION:
HE98	28	SE ¼, south line	Base Altamont Limestone (Amoret Lst. Mbr.) 960 ft. ASL.
HE99	32	NE ¼, east line	Possible top of Altamont Limestone (Worland) 993 ft. ASL.
HE100	32	SW/NW/NW/NW	Base Altamont Limestone (Amoret Lst. Mbr.) 980 ft. ASL.
HE101	32	NW/NW, north line,	Upper Bandera Shale sandstone bed.
HE102	32	NW ¼, north line	Upper Bandera Shale sandstone bed.

T.28S., R.23E.

SITE:	SEC:	LOCATION:	DESCRIPTION:
HE103	3	Near C, north line	Altamont Limestone (unknown member) in creek bed.
HE104	4	NW/NE, north line	Upper Altamont Limestone (Worland Lst. Mbr.) crossing road from north to south.

HIATTVILLE QUADRANGLE

T.26S., R.23E.

SITE:	SEC:	LOCATION:	DESCRIPTION:
HI1	25	Near SE corner	Anna Shale/Myrick Station contact (in the Pawnee Limestone), 890 ft. ASL (West and Sawin, 1997).
HI2	26	SW ¼, near C, south line	Large slab of upper Pawnee Limestone (Laberdie), north side of road, long exposure of medium gray limestone.
HI3	26	Near SE corner	Near the top of the Pawnee Limestone (Laberdie) approx. 930 ft. ASL (West and Sawin, 1997).
HI4	27	Near SE corner	Limestone crossing road, probably lower Altamont (Amoret), near the contact with Bandera Shale estimated at 935 ft. ASL.
HI5	27	SE ¼, south line	Base Altamont Limestone (Amoret) estimated at 975 ft. ASL due to cover (West and Sawin, 1997).

T.27S., R.23E.

SITE:	SEC:	LOCATION:	DESCRIPTION:
HI6	2	S of C, west line	Base Altamont Limestone (Amoret), 980 ft. ASL, with Bandera Shale in ditch (West and Sawin, 1997).
HI7	3	NE ¼, east line	Altamont Limestone crossing road.
HI8	3	Near SE corner	Base Altamont Limestone (Amoret), 980 ft. ASL, with Bandera Shale beneath (West and Sawin, 1997).
HI9	10	NE ¼	Lenapah Limesone, prob, Perry Farm Shale Member.
HI10	10	NE ¼, east line	Altamont Limestone crossing road.
HI11	11	E of C, south line	Base of Pawnee Limestone (Myrick Station Lst. Mbr.), 920 ft. ASL West and Sawin, 1997).
HI12	12	SE/SE/SW/SE	Top of Anna Shale, base of Myrick Station Limestone, 908 ft. ASL (West and Sawin, 1997).
HI13	15	NE ¼, east line	Pawnee Limestone in road (West and Sawin, 1997).
HI14	15	Near SE corner	Labette Shale, gray, silty mudstone in creek (West and Sawin, 1997).
HI15	22/23	SE ¼, Sec. 22 and SW ¼, Sec. 23	Base Altamont Limestone (Amoret), 975 ft. ASL,. (Contact) forms crest of hill that bends around and crosses the road several times as it follows terrain.
HI16	25	NW ¼, west line	Base Altamont Limestone (Amoret), 990 ft. ASL.
HI17	27	SW/NW	Base Altamont Limestone (Amoret), 980 ft. ASL, continued trace identified at HI15.
HI18	34	SE corner	Altamont Limestone in road ditch.
HI19	36	E of C, north line	Base Altamont Limestone (Amoret) 990 ft. ASL.

T.28S., R.23E.

SITE:	SEC:	LOCATION:	DESCRIPTION:
HI20	1	NE/NE, north line	Base Altamont Limestone (Amoret), estimated 1012 ft. ASL.

T.28S., R.23E. (continued)

SITE:	SEC:	LOCATION:	DESCRIPTION:
HI21	1	W of C, north line	Limestone float observed south of road, Base of Altamont estimated at 1010 ft. ASL.
HI22	2	NE/NE, north line	Bandera Shale/Altamont Limestone (Amoret) contact, 1005 ft. ASL.