STRATIGRAPHY, PETROLOGY,DEPOSITIONAL ENVIRONMENTS, AND DIAGENESIS OF THE HEPLER FORMATION (PLEASANTON GROUP, UPPER PENNSYLVANIAN) IN SOUTHEASTERN KANSAS

by

Michael H. Gilmer

A thesis submitted in partial fulfillment
of the requirements for the Master of
Science degree in Geology
in the Graduate College of
The University of Iowa

May 1993

Thesis supervisor: Associate Professor Robert L. Brenner

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The University of Iowa
Iowa City, Iowa

CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

Michael H. Gilmer

has been approved by the Examining Committee
for the thesis requirement for the Master of Science
degree in Geology at the May 1993 graduation.

Thesis committee: Robert L Brenner
Thesis supervisor

Greg Ludvigson
Member

Philip H Heckel
Member

ABSTRACT

The Hepler Formation marks the base of the Pleasanton Group which is recognized as the base of the Upper Pennsylvanian in southeastern Kansas. This formation consists of interstratified units of shales, siltstones, and sandstones, as well as localized coal beds. These lithologies are interpreted as having formed in a prograding deltaic/fluvial sequence that was deposited as the Late Pennsylvanian sea temporarily withdrew from the Cherokee shelf. Four lithofacies are recognized in the Hepler Formation: 1) very fine-to-medium grained, calcite-cemented quartz sandstone; 2) interstratified, bioturbated, carbonaceous siltstone and shale;3) interstratified convoluted sandstone, siltstone, and shale; and 4) carbonaceous blocky mudstone/coal. Hepler sandstones in the study area are prdominately quartz arenites and sublitharenites.

The diagenetic history of the Hepler consisted of alternating periods of authigenic mineral precipitation and dissolution of both detrital grains and cements. Petrographic observations indicate silica cementation, in the form of quartz overgrowths, and calcite cementation took place early in the paragenetic sequence. Early cementation of sediments hindered further diagenetic and compactional effects. Changes in meteoric water chemistry, resulted in partial quartz and feldspar dissolution, and alteration of feldspars to clays. Further burial and compaction initiated a second stage of carbonate cementation and the formation of kaolinite and chlorite clays. This was followed by anoxic conditions which allowed pyrite crystallization to take place. A subsequent fall in sea level exposed Hepler deposits once again to meteoric, low pH waters, resulting in carbonate dissolution. Surface samples were subject to weathering of iron-bearing components to iron-oxide, a product not observable in subsurface core samples.

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Geologic Setting

Location of Study Area

Twenty-three counties encompass the study area in southeastern Kansas (figure 1). Hepler Formation outcrop exposures occur within the Pleasanton Group (Missourian; lower Upper Pennsylvanian) outcrop belt that trends southwest to northeast in southeastern Kansas through parts of Montgomery, Labette, Neosho, Crawford, Bourbon, Linn and Miami Counties. The Kansas Geological Survey provided approximately 580 geophysical logs from wells and six well cores located west of the outcrop belt for examination (Figure 1).

Tectonic Features

The midcontinent east of the ancestral Rocky Mountains was subject to regional deformation in the Early Pennsylvanian (Kluth and Coney, 1981). Eastern Kansas in early Pennsylvanian time was a low-lying area of positive relief, where lower Paleozoic rocks were exposed. The positive structural elements that affected the region are the Nemaha Uplift and Bourbon Arch (Merriam, 1963) (Figure 2).

In eastern Kansas, the NNE to SSW trending Nemaha Uplift separates the Salina Basin on the west from the Forest City Basin-Cherokee Shelf to the east (Merriam, 1963). The Bourbon Arch, trending WNW to ESE, separates the

Figure 1. Location of study area in souitheastern Kansas. Pleasanton Group outcrop belt, distribution of well logs, core, and cross section locations are shown. X's correspond to outcrop localities. Dots correspond to well log locations. Dots enclosed by squares refer to well logs used in cross section construction. Circled dots correspond to well log with core. Counties: Mi=Miami; Fr=Franklin; Os=Osage; Ly=Lyon; Mor=Morris; Ma=Marion; Ch=Chase; Co=Coffey; An=Anderson; Li=Linn; Bo=Bourbon; Al=Allen; Wo=Woodson; Gr=Greenwood; Bu=Butler; Cw=Cowley; El=Elk; Wi=Wilson; Ne=Neosho; Cr=Crawford; La=Labette; Mo=Montgomery; Cha=Chautauqua.

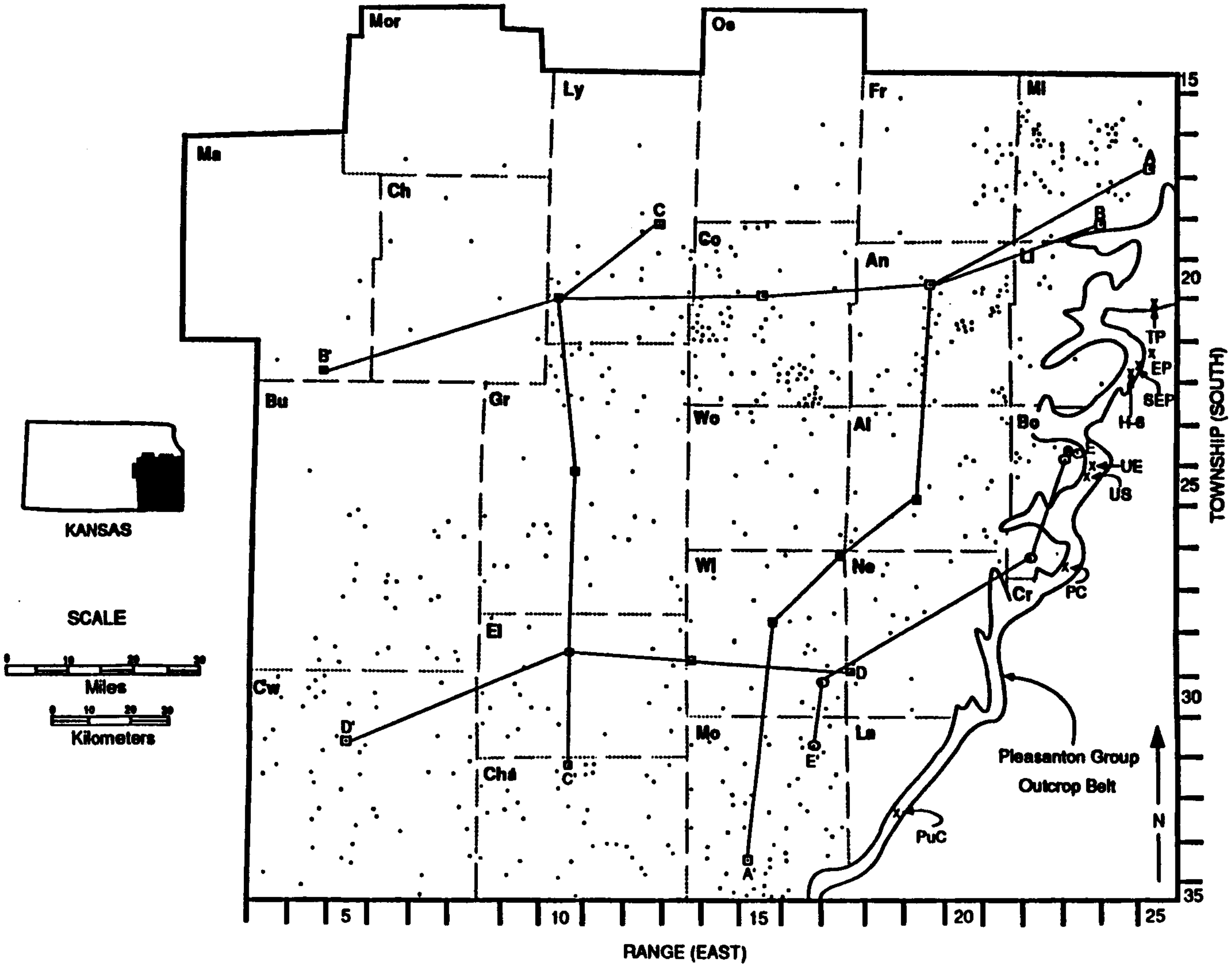
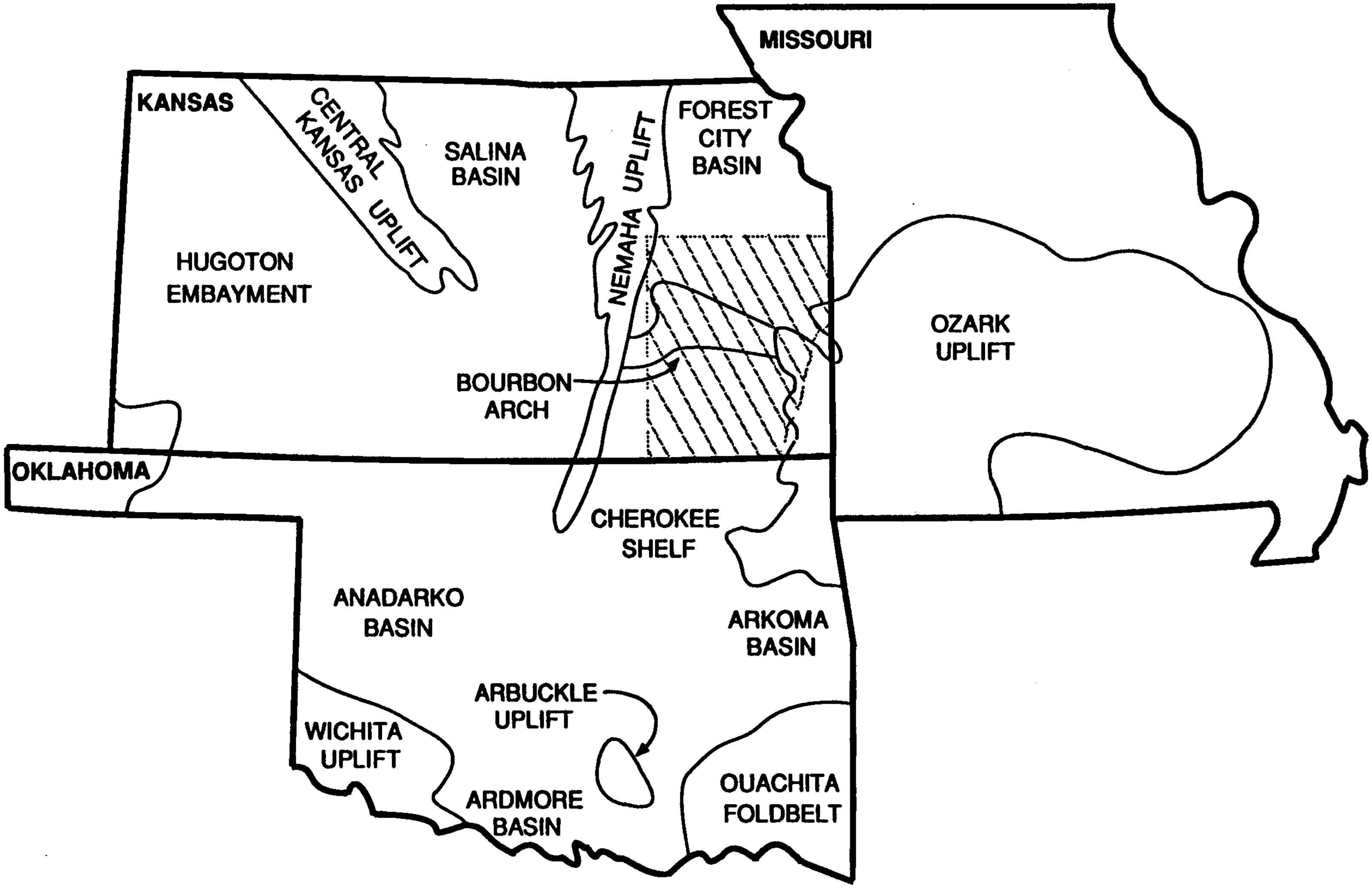

Mor
Os
Ma
Ly
Fr
Mi
Ch
Co
An
Bu
Gr
Wo
Al
Bo
Wl
Ne
Cr
El
Cw
Mo
La
Cha
Li
A
A'
B
B'
C
C'
D
D'
E
E'
TP
EP
SEP
H-8
UE
US
PC
PuC
Pleasanton Group
Outcrop Belt
N
KANSAS
SCALE
0
10
20
30
Miles
Kilometers
15
20
25
30
35
TOWNSHIP (SOUTH)
5
10
15
20
25
RANGE (EAST)

Figure 2. Basement structure of the Mid-Continent (after Rascoe and Adler, 1983)

[redacted]


MISSOURI
KANSAS
CENTRAL KANSAS UPLIFT
SALINA BASIN
NEMAHA UPLIFT
FOREST CITY BASIN
HUGOTON EMBAYMENT
OZARK UPLIFT
BOURBON ARCH
OKLAHOMA
CHEROKEE SHELF
ANADARKO BASIN
ARKOMA BASIN
ARBUCKLE UPLIFT
WICHITA UPLIFT
ARDMORE BASIN
OUACHITA FOLDBELT

Cherokee Shelf to the south from the Forest City Basin to the north. They in turn are bounded on the east by the Ozark Uplift (Merriam, 1963; Rascoe and Adler, 1983).

During Middle and Late Pennsylvanian time, the Cherokee Shelf remained a tectonically stable area in southeastern Kansas. Marine environments developed in eastern Kansas during periods of transgression resulting from glacial eustatic sea level fluctuations (Wanless and Shepard, 1936; Heckel, 1980). Regression brought prograding deltaic sediments across the Cherokee shelf.

Previous Investigations

The Pennsylvanian System comprises five stages in ascending order: Morrowan, Atokan, Desmoinesian, Missourian, and Virgilian. The Hepler sandstone forms the base of the Pleasanton Group (Missourian: lower Upper Pennsylvanian), which crops out across southeastern Kansas (Jewett, 1940 ; Jewett et. al., 1965). In Kansas, the Pleasanton Group has been divided into 3 formations in ascending order: Seminole Formation, Checkerboard Limestone, and Tacket Formation (Jewett, et al.,1965). The Hepler sandstone was originally defined by Jewett (1940) and is historically recognized as a fine-grained, micaceous, calcite-cemented sandstone with local coals, which disconformably truncate sediments of Desmoinesian age (Jewett 1940; Moore et. al. 1944). Jewett designated the type section for the Hepler sandstone just north of the town of Hepler (ctr sec.14, T27S, R22E) in southern Bourbon County southeast of location PC on Figure 1.

Jewett's type section has since been shown to occur within the Lenapah Limestone of Desmoinesian age (Sutton, 1985; Heckel, 1991).The Hepler sandstone had been incorrectly used as a marker bed by early workers that referred to any sandstone near the Desmoinesian-Missourian boundary as "Hepler" and treated it as a single persistent bed. These errors were due in part to poor outcrop exposures, limited stratigraphic control, and a lack of knowledge about sandstone geometries. Sutton (1985) concluded that sandstones at three stratigraphic horizons had been incorrectly identified as the Hepler sandstone in southeastern Kansas. The stratigraphic location of Sutton's Hepler "C" was found to be the interval generally regarded as Hepler in most of Kansas and Missouri. A new reference section (neostratotype) has been designated along Rt 39 about 2 miles northwest of the original Hepler type section (Heckel, manuscript in review). The Hepler has been redefined as a "formation that encompasses all strata in the Pleasanton Group between the marine Lost Branch Formation and the base of the marine Exline Limestone" ; it is now regarded as including the South Mound Shale member where it is present toward the south (Heckel, manuscript in review; see Sutton 1985), but the South Mound is excluded from the present study

Purpose of Study

This study will focus on the sedimentological and diagenetic history of the Hepler Formation in the Pleasanton Group. It's objectives include:

1) Documentation of the composition and textures of the Hepler sandstone by petrographic examination of surface exposures and well cores. 2) Reconstruction of the depositional environment of the Hepler Formation.

3) Interpretation of the diagenetic history of the formation. 4) Examination of facies relationships within the Hepler and their relationship to regional stratigraphy. 5) Interpretation of the provenance of the Hepler Formation with current data that was unavailable in early studies. 6) Petrographic comparison between the traditional Hepler sandstone (Sutton Hepler "C") and the other intervals of sandstone near the Desmoinesian-Missourian boundary.

Methods of Study

Physical Analysis

Fieldwork performed during May 1991 included examination of 8 outcrop localities in southeastern Kansas along the Pleasanton Group outcrop belt and six cores provided by the Kansas Geological Survey. Outcrop and cores were measured and descriptions of lithologies and sedimentary structures were recorded. Sampling occurred throughout the interval in both the outcrop locations and core for thin section petrography and S.E.M. analysis.

Petrographic Analysis

Thirty-three thin sections were examined, representing 3 different stratigraphic sandstone horizons near the Desmoinesian-Missourian boundary in southeastern Kansas. Of the 33 thin sections, 24 were from outcrop exposures and 9 were from continuous cores. Prior to being thin-sectioned, trimmed blanks were impregnated with blue-dyed epoxy resin to prevent plucking of grains and thus preserving an accurate representation of the samples present porosity. Thin-sections were stained with alizarin red-S and potassium ferricyanide (Lindholm and Finkleman, 1971) to discriminate calcite from dolomite and recognize the presence of ferroan carbonates. A petrographic microscope was used to determine grain composition, cements, texture, sorting and to observe diagenetic features of the Hepler Formation. Based on a modal analysis of 250 grid points per thin-section, sandstone classification was performed using Folk's scheme (1974). Grain contact indices were determined by examining 50 grains per thin section. Packing densities and packing proximity percentages were calculated using Kahn's (1956) procedures.

Scanning Electron Microscopy

Both core and outcrop samples were examined by S.E.M. and analyzed to determine grain and pore morphologies, overgrowths, cements, and diagenetic features. Samples were cut into approximately 15 mm. cubes, scored, fractured and mounted on aluminum stubs. Samples were carbon coated to prevent charging. The accelerating voltage ranged between 10-15 Kv. Mineral identification was aided by energy dispersive x-ray microanalysis.

Geophysical Analysis

Approximately 580 gamma-ray and neutron density well logs from the study area were examined from the repository at the Kansas Geological Survey. A geophysical signature of the well is produced by the log curve that records emitted gamma-radiation from a process of radioactive decay of naturally occurring materials. A significant amount of natural radiation in sedimentary rocks occurs from : 1) the uranium-radium decay series, 2) thorium decay series, and 3) fission of Potassium 40. Both feldspars and micas contain a large percentage of the earth's potassium fraction. Decomposition of this mineral group yields clay minerals that are incorporated into fine-grained mudrocks. Fine-grained mudrocks are recorded as a high gamma-ray count and are indicated as deflections to the right on gamma-ray logs. Most phosphatic black shales in southeastern Kansas are identified by their particularly strong gamma-ray deflections to the right. Carbonate rocks generally have a low gamma-ray count and are recorded as strong deflections to the left. Gray shales in the study area generally have moderate gamma-ray counts and deflections fluctuate between the those of the aforementioned lithologies. Sandstone gamma-ray counts and deflections generally fall between those of shales and limestones.

Gamma-ray logs are used as indicators of shale-free zones. With grain size and shaliness of sandstones reflecting the energy of the environment of deposition, a shale-free formation (i.e. clean sandstone) indicates depositional conditions with stable currents that winnowed grains of fine-grained clay minerals. Radioactive response on the gamma-ray well log to shaly sandstones is high compared to clean sands. These relationships allow lithologic interpretations to be made from gamma-ray-neutron log signatures.

Well-log signatures were calibrated by comparing them to core descriptions of Hepler Formation lithologies, this allowed depositional and stratigraphic relationships interpreted on outcrop and well cores to be extrapolated throughout the study area via the 580 well logs. Within and constraining the Hepler Formation, 4 lithologies are identifiable on the gamma-ray-neutron log : black shale, shale, sandstone, and limestone. These well-log signatures, corresponding lithologies, and stratigraphical knowledge provide a framework for subsurface correlation and interpretation of the Hepler in southeastern Kansas.

The Nuyaka Creek black shale and Mound City black shales are laterally continuous and easily recognizable on well-logs in the study area (Figure 3). These persistent marker horizons provide a stratigraphic framework for well to well subsurface correlations. The Nuyaka Creek black shale served as the datum for cross-section construction.

Two isopach maps were constructed. One isopach map indicates the thickness of the interval between the basal Nuyaka Creek black shale and the Mound City black shale of the overlying major cyclothem. A second isopach map shows the interval between the basal Nuyaka Creek black shale marker horizon and the top of the traditional Hepler Sandstone marked by the Exline limestone or the South Mound shale in the southern portion of the field area.

Construction of the Hepler Formation sandstone isolith map was accomplished by generating a shale base line that corresponds to gamma-ray values that coincide with gray shales observed in cores. A clean sand line was constructed at gamma-ray values that coincided with clean sandstones observed in cores. A 50 percent sand line was constructed, indicating the area to the left of the line is composed of greater than 50 percent sand sized material. Thicknesses along the line were recorded and used to construct the sandstone isolith map.

STRATIGRAPHIC OVERVIEW AND LITHOFACIES DESCRIPTIONS

Stratigraphic Overview of the Study Area

Cyclic sedimentation dominated the Middle and Late Pennsylvanian of the Midcontinent. These repeating intervals of alternating carbonate and siliciclastic deposits have been interpreted as transgressive-regressive depositional cycles that formed in response to glacio-eustatic sea-level fluctuations (Heckel, 1986). The maximum offshore transgressive high-stand deposits within each cycle are represented by phosphatic black shales. Regressive nearshore and terrestrial low-stand deposits include sandy shales, siltstones, fine-grained to coarse-grained sandstones, paleosols, and coals.

The part of the Hepler Formation studied is overlain by the transgressive marine Exline Limestone member (Shale Hill Formation) to the north and the marine South Mound Shale member in southernmost Kansas (Heckel, manuscript in review). Hepler Formation sediments overlie the transgressive, high-stand, and early regressive marine deposits of the Lost Branch Formation (Marmaton Group) (Figure 3). The Lost Branch Formation is the highest Desmoinesian marine unit and contains the phosphatic Nuyaka Creek black shale, a persistent marker bed that is easily identified on outcrop and in the subsurface on geophysical logs in southeastern Kansas.

Figure 3. Stratigraphic column of the Pleasanton Group and position of the Hepler Formation in Kansas. Mound City shale Member of the overlying Hertha Limestone (Kansas City Group) and Nuyaka Creek Shale Bed of the Lost Branch Formation (Marmaton Group) are shown in black. Note: Although the South Mound Shale Member is considered part of the Hepler Formation, it is not included in this study. Modified from Heckel, 1984 and ms. in review.

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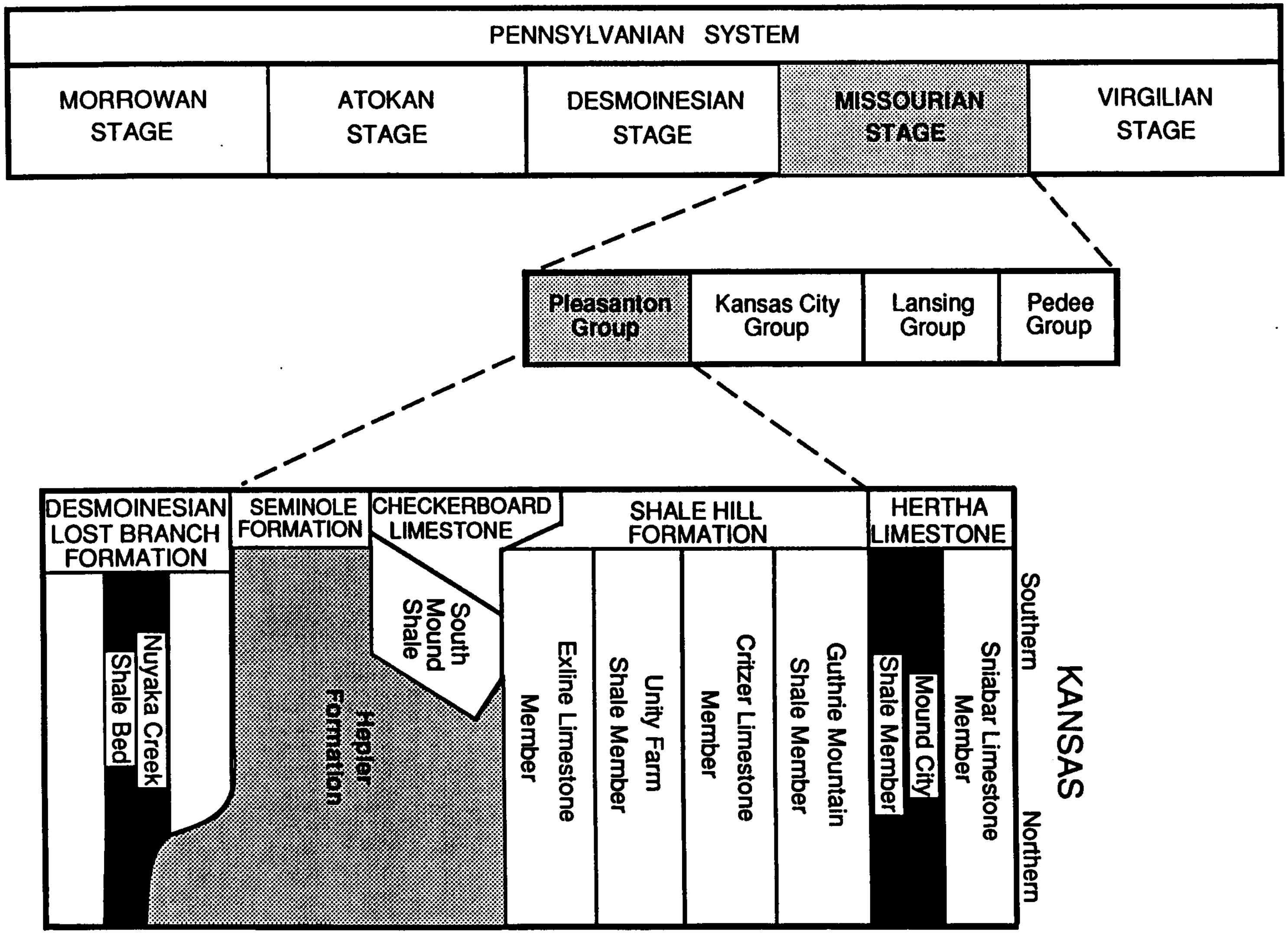

PENNSYLVANIAN SYSTEM
MORROWAN STAGE
ATOKAN STAGE
DESMOINESIAN STAGE
MISSOURIAN STAGE
VIRGILIAN STAGE
Pleasanton Group
Kansas City Group
Lansing Group
Pedee Group
DESMOINESIAN LOST BRANCH FORMATION
Nuyaka Creek Shale Bed
SEMINOLE FORMATION
Hepler Formation
CHECKERBOARD LIMESTONE
South Mound Shale
SHALE HILL FORMATION
Exline Limestone Member
Unity Farm Shale Member
Critzer Limestone Member
Guthrie Mountain Shale Member
HERTHA LIMESTONE
Mound City Shale Member
Sniabar Limestone Member
Southern
Northern
KANSAS

The Hepler Formation is a low-stand regressive to terrestrial deposit containing silty shales, siltstones, sandstones and localized coals. These deposits prograded across the Cherokee Shelf as the sea withdrew from the shelf area at the end of the Desmoinesian, and continued accumulating in some places during subsequent lowstand in the early Late Pennsylvanian.

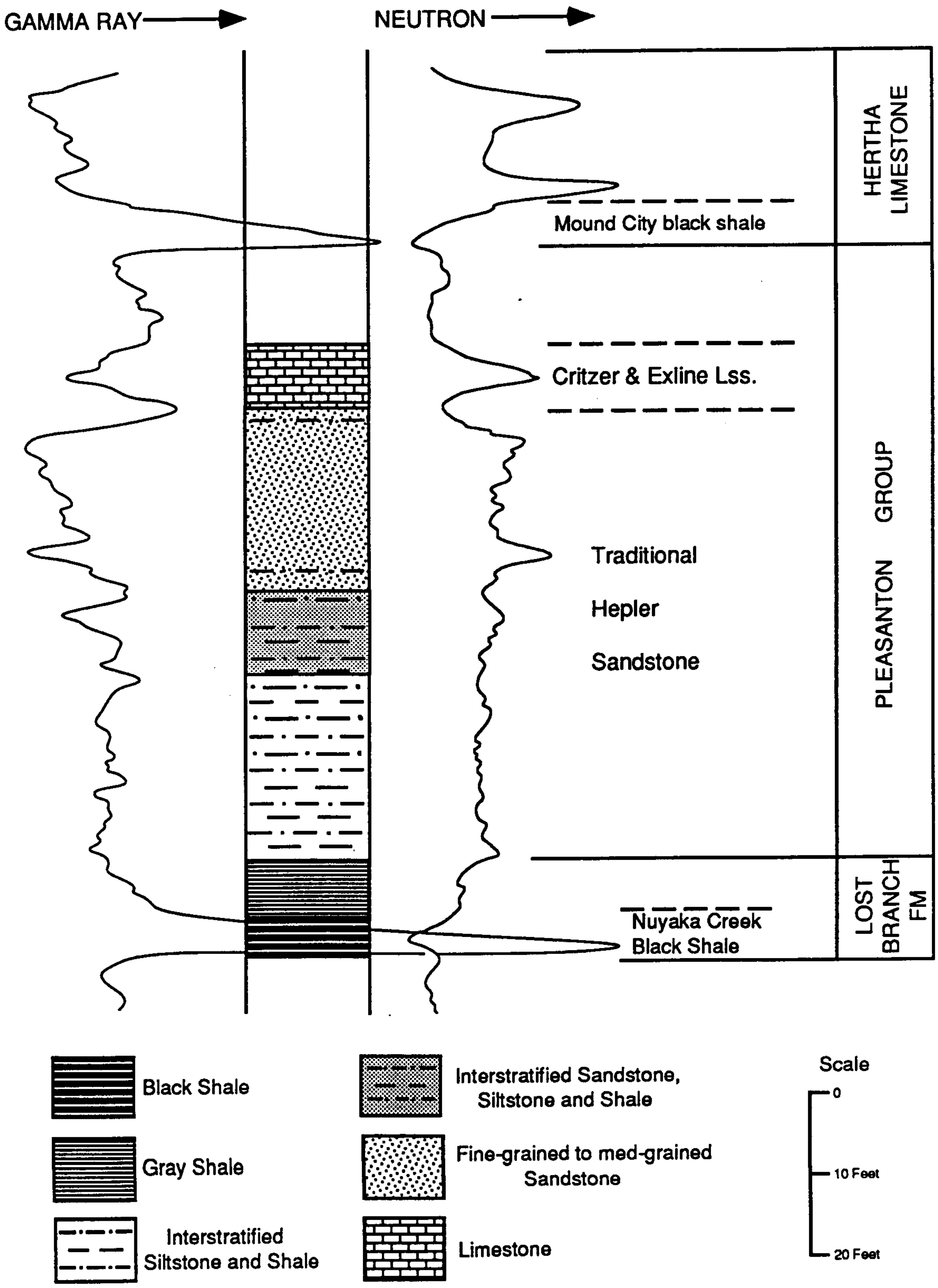
Subsurface Stratigraphic Relationships

Core and Geophysical Well Log Analysis

Subsurface analysis of the Hepler Formation involved cores and geophysical well logs supplied by the Kansas Geological Survey. Approximately 580 gamma-ray-neutron-density well logs and six cores, from the study area, were used in the analysis. The six cores were examined and their lithologic and sedimentologic characteristics were described. The descriptions were then compared to their corresponding gamma-ray and neutron log signatures.

Identifcation and stratigraphic postioning of the Hepler Formation in the subsurface was based on identifying the Nuyaka Creek black shale bed of the Lost Branch Formation on geophysical well logs. This phosphatic black shale has a distinctive high gamma-ray spiked signature (Figure 4). The Nuyaka Creek black shale underlies the Hepler Formation and is underlain by several thin units, then the Altamont Limestone, a distinctive limestone easily identified on geophysical well logs of the study area. The Nuyaka Creek is overlain by a gray transitional marine shale (upper part of Lost Branch Formation) that is indicated by a high but decreasing gamma-ray count. This gray shale is in turn overlain by

Figure 4. Gamma-Ray and Neutron logs of cored well (Troike #1, the Prong Creek core of Heckel,1991) in southwestern Bourbon County. The logs show the characteristic signatures of Hepler lithologies recognized in core and described in the appendix. Note the distinctive high gamma-ray count for both of the black shales illustrated. Both black shales were used as marker beds or subsurface correlation.


GAMMA RAY
NEUTRON
HERTHA LIMESTONE
Mound City black shale
Critzer & Exline Lss.
Traditional
Hepler
Sandstone
PLEASANTON GROUP
LOST BRANCH FM
Nuyaka Creek Black Shale
Black Shale
Gray Shale
Interstratified Siltstone and Shale
Interstratified Sandstone, Siltstone and Shale
Fine-grained to med-grained Sandstone
Limestone
Scale
0
10 Feet
20 Feet

the sediments of the Hepler Formation.

The sediments of the Hepler Formation are characterized by an irregular, decreasing-count upward pattern on the gamma-ray logs that indicates a coarsening upward sequence (Figure 4). The overlying Exline Limestone, in the area where the core was extracted, is shown as a thin, spiked, low gamma-ray signature (Figure 4). Overlying the Exline Limestone are the shales of the Shale Hill Formation (including the thin Critzer Limestone),which are in turn overlain by the Mound City black shale of the Hertha Formation. The Mound City black shale is easily identified by its high gamma-ray spiked signature (Figure 4).

Two isopach maps were constructed based upon well log characteristics, lithologies, and stratigraphic positioning. The first isopach map shows the regional extent and variable thickness of the entire Pleasanton interval between the Nuyaka Creek black shale and the overlying Mound City black shale in the study area (Figure 5). This isopach map indicates that sediments thin from the east, northeast to the west and south. The second isopach map, constructed using the interval between the Nuyaka Creek black shale and the base of the Exline Limestone in the north or the base of the South Mound Shale Member in the south, shows the regional variability of just the Hepler Formation in the subsurface of southeastern Kansas (Figure 6). The net isopach map of Hepler sediments indicates a thinning east to west trend with the thickest sediment occuring in the east near the Pleasanton Group outcrop belt (Figure 6). The Hepler isopach map indicates a division within the study area in which a northern and southern lobe are separated by an area of low sedimentation of less than 10 feet. Within each lobe, areas of variable Hepler sedimention thicknesses are observed attaining as much as 50 feet in thickness.

Figure 5. Isopach map of Pleasanton interval from the Nuyaka Creek Shale to Mound City Shale. Contour interval equals 20 feet.

[redacted] [redacted] [redacted]

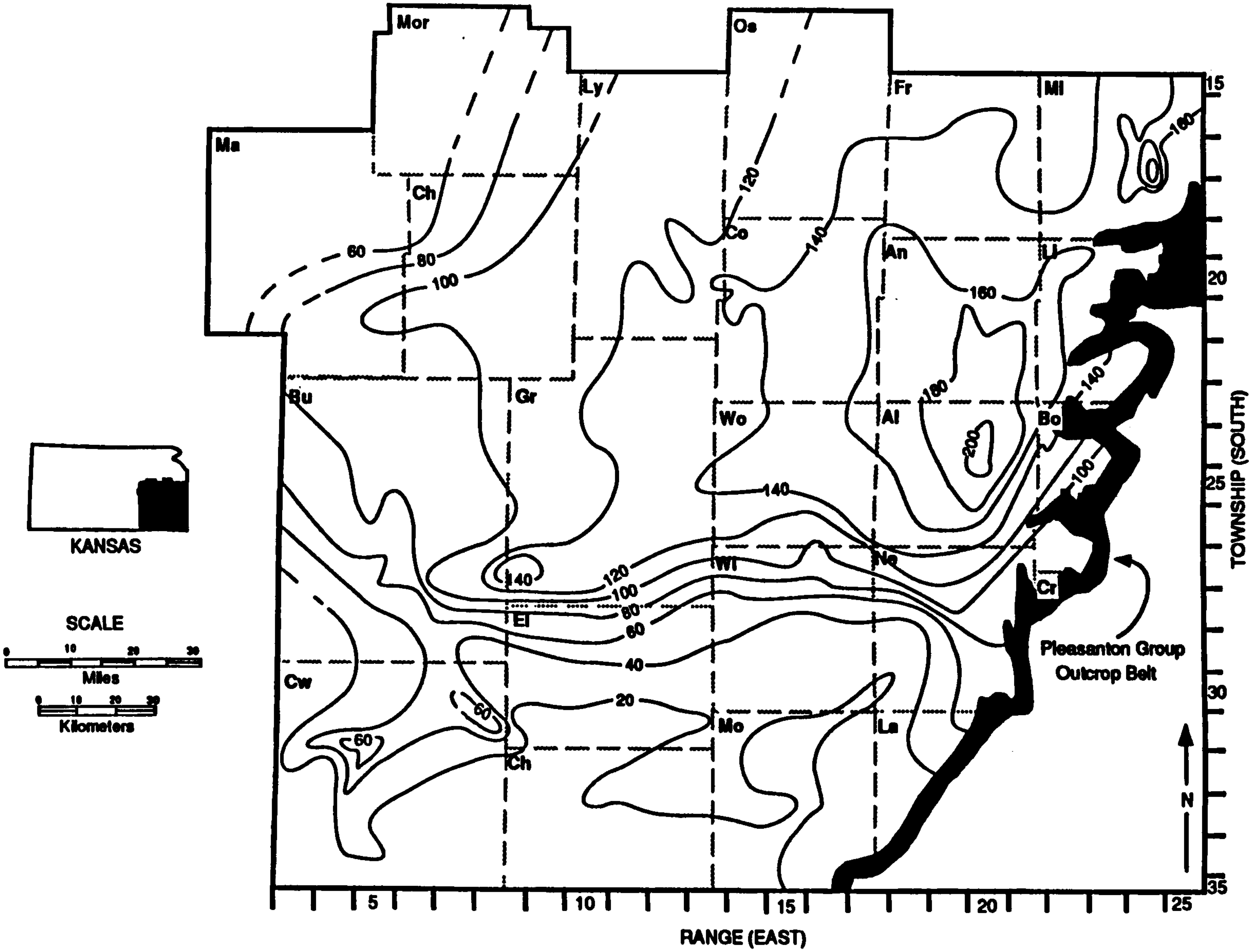


Figure 6. Isopach map of Hepler interval from Nuyaka Creek Shale to base of Exline Limestone in north and or base of the South Mound Shale in south. Contour interval equals 10 feet.

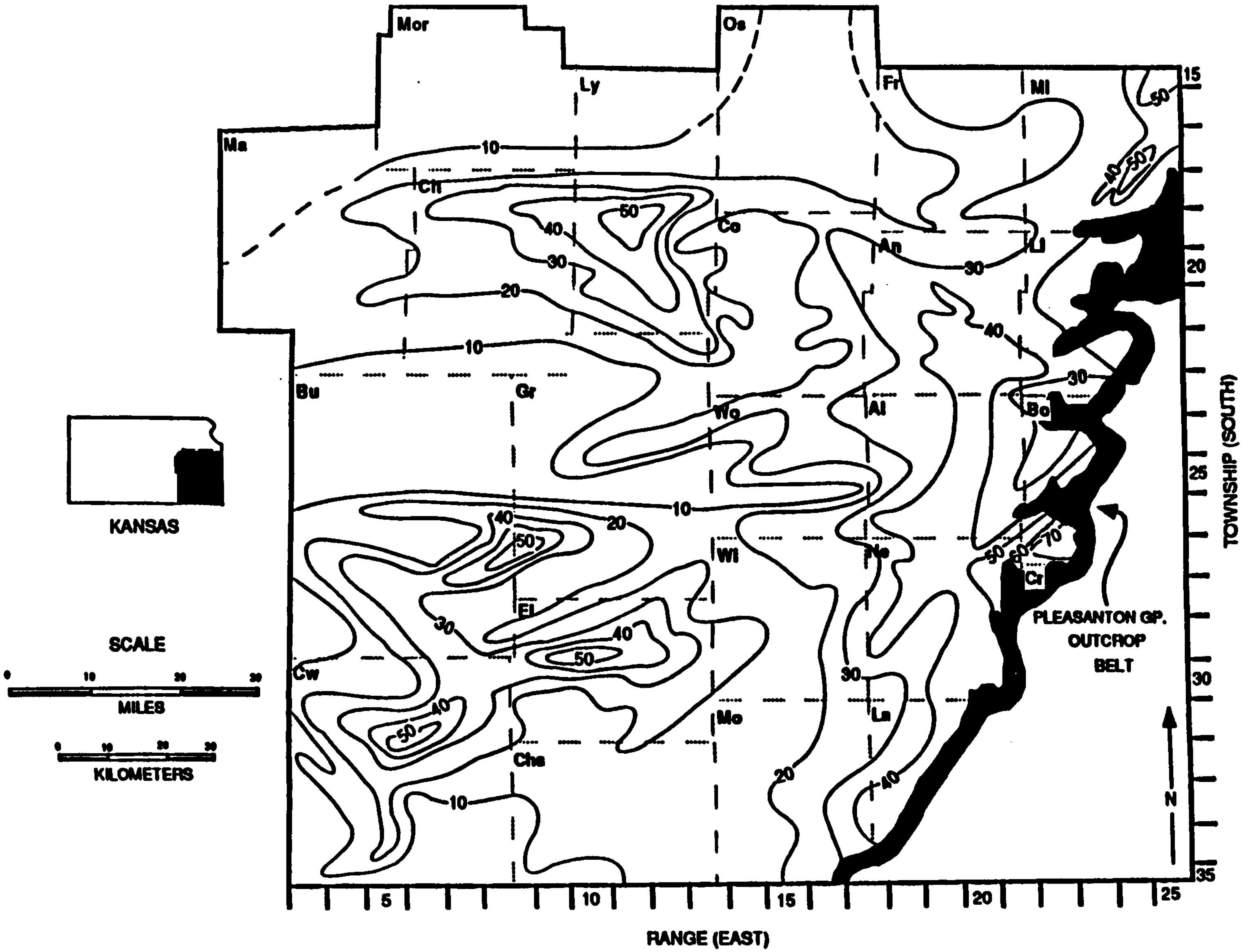
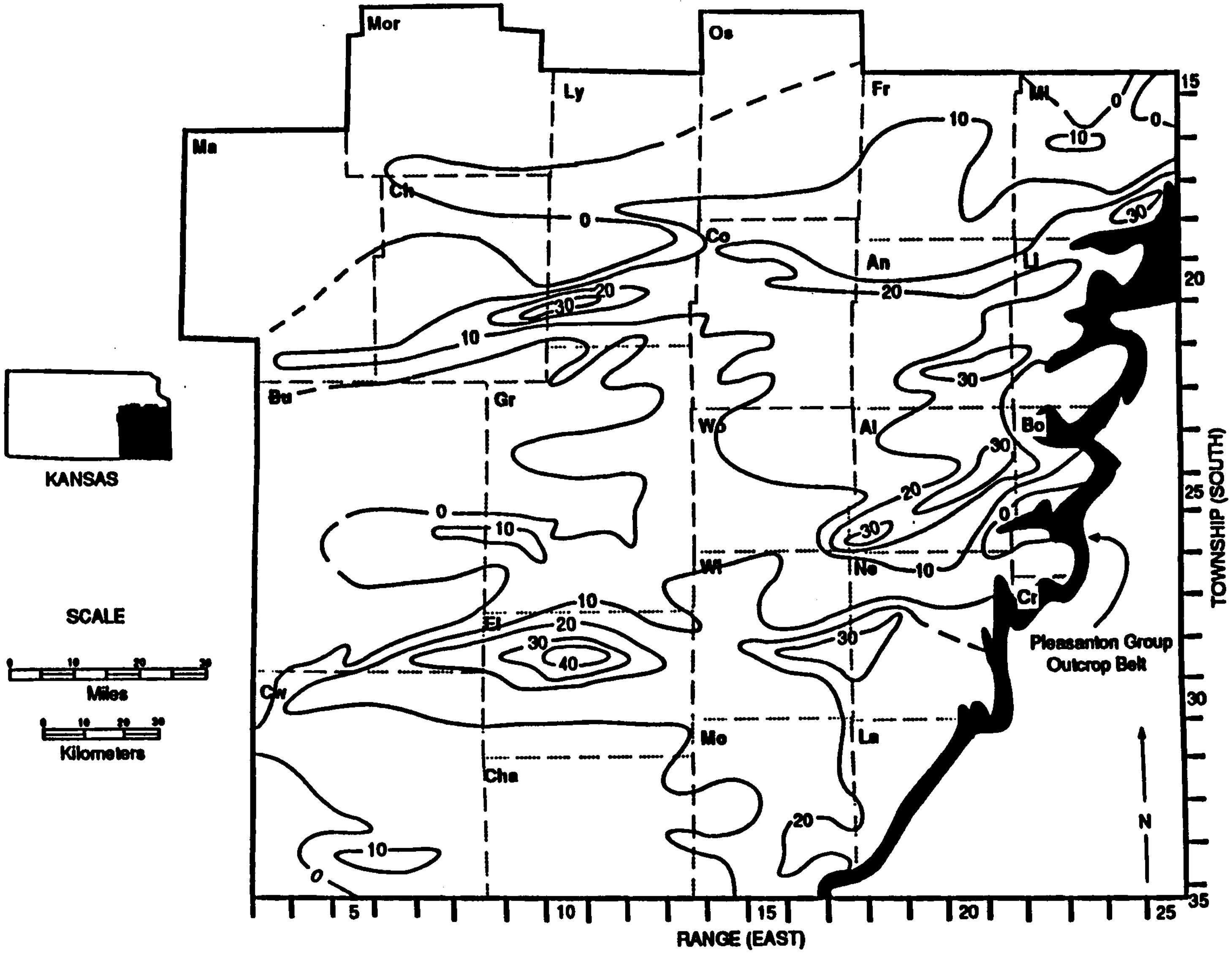

Mor
Os
Ly
Fr
Mi
Ma
Cf
Co
An
Li
Bu
Gr
Wo
Al
Bo
Wi
Ne
Cr
El
Cw
Mo
La
Chs
10
20
30
40
50
60
70
PLEASANTON GP. OUTCROP BELT
KANSAS
SCALE
0 10 20 30
MILES
0 10 20 30
KILOMETERS
N
TOWNSHIP (SOUTH)
15
20
25
30
35
RANGE (EAST)
5
10
15
20
25

Figure 7. Net sandstone isolith of Hepler Formation in southeastern Kansas.
Contour interval equals 10 feet.

[redacted]

[redacted]



A net Hepler sandstone isolith map was constructed to show sandstone distribution in the subsurface, using the previously discussed method outlined in Brenner and McHargue (1988)(Figure 7). The sandstone isolith map indicates a thinning of the sandstone interval from east to west. The sandstones are linear features in the map area attaining 30 to 40 feet in thickness within both of the previously discussed lobes of the Hepler Formation in the subsurface of southeastern Kansas.

Cross-Section Relationships

Cross-sections A-A' and C-C' (Figure 8) run along a north/south trend in the field area and cross-sections B-B' and D-D' (Figure 9) run along an east/west trend. Cross-sections B-B' and D-D' were constructed to follow the linear features produced on the sandstone isolith map and are perpendicular to both A-A' and C-C'.Cross-section construction is based on the inerval between the Nuyaka Creek black shale and the Mound City black shale. All cross-sections use the Nuyaka Creek black shale as the datum.

The cross-sections show a thinning of the traditionally recognized Hepler Sandstone to the west and to the south. Within the traditional Hepler Sandstone, most of the well log signatures contain a coarsening upward or "funnel-shaped" signature. Most thickness variability in the interval occurs in the overlying undifferentiated Pleasanton shales.

Lithofacies Descriptions

A total of 5 lithofacies are identified in the study area above the Nuyaka Creek black shale bed.The Hepler Formation can be subdivided into 4 lithofacies

Figure 8. Cross-section A-A' and B-B'. Lateral continuity of black shales and Hepler Formation in northern section of study area. Location of cross-section on figure 1.

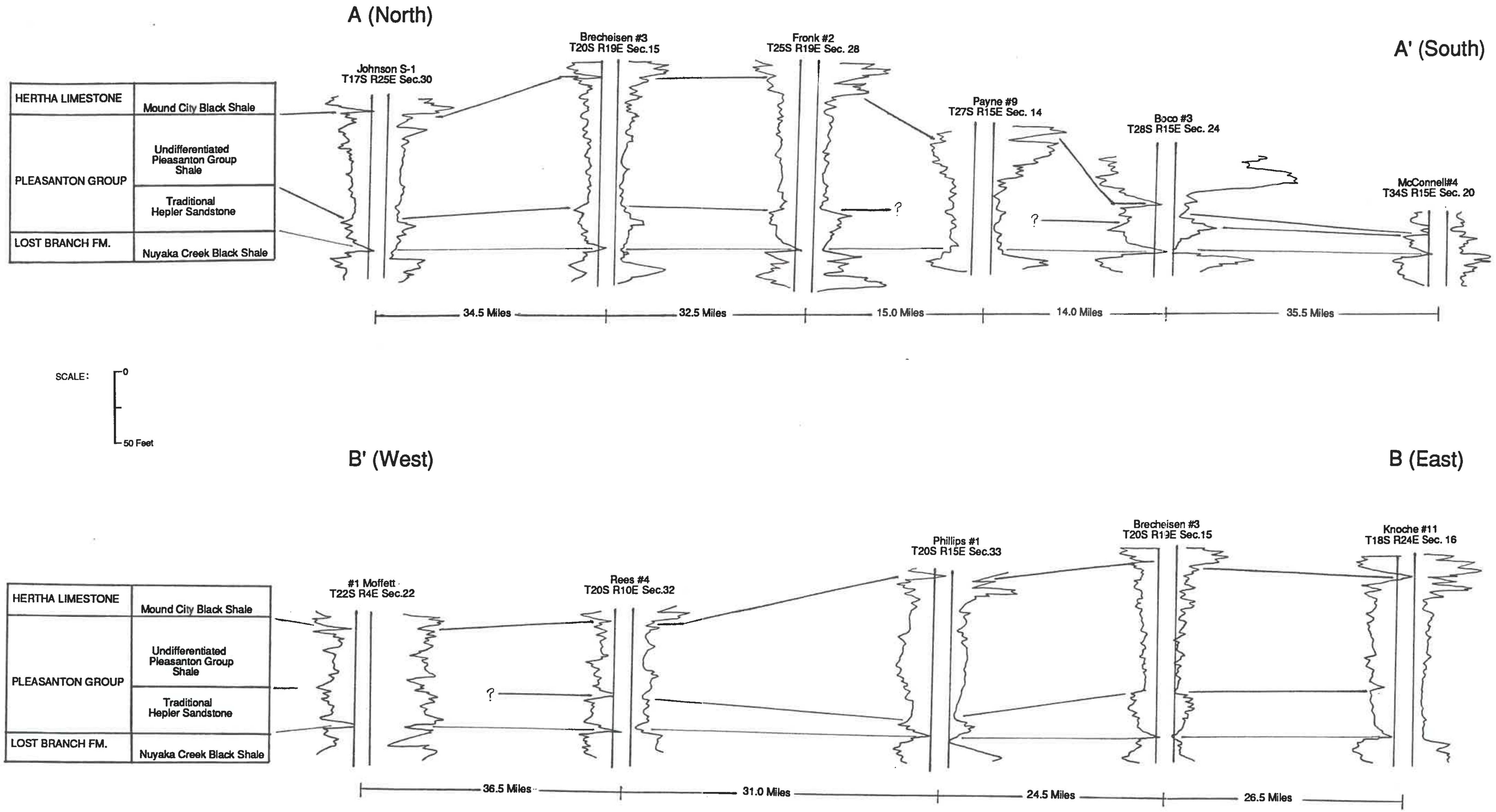
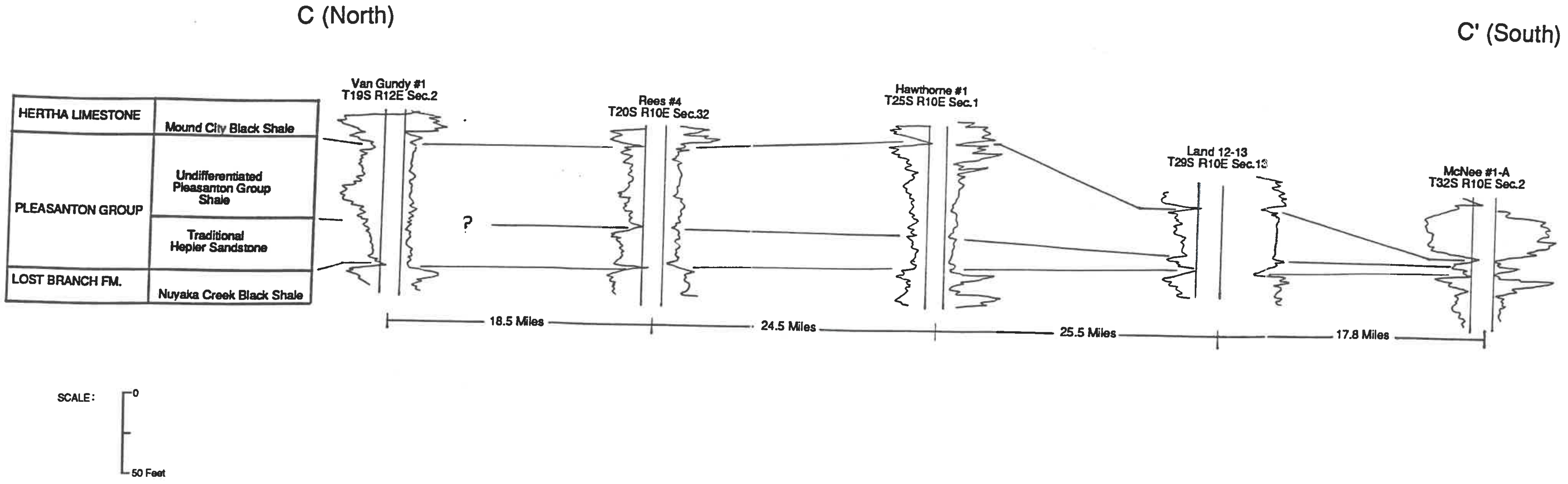
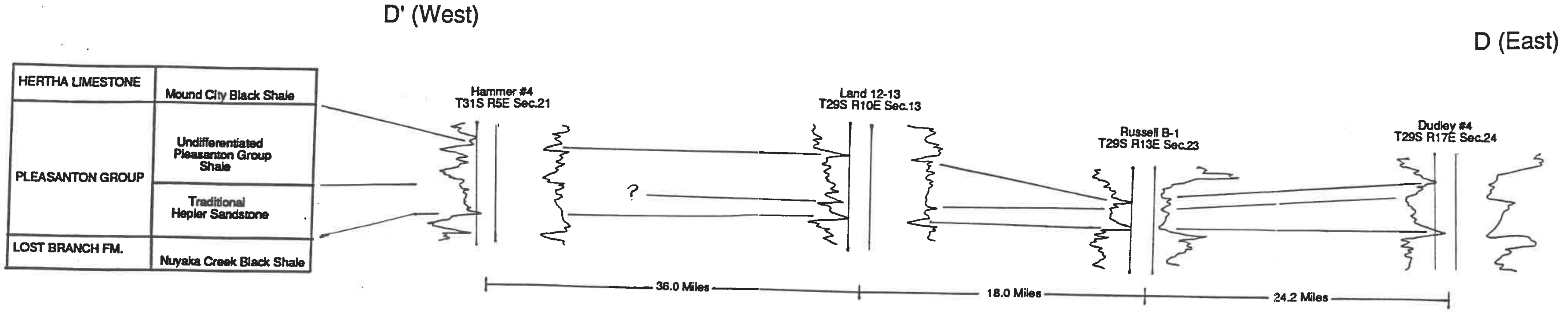

A (North)
A' (South)
HERTHA LIMESTONE
Mound City Black Shale
PLEASANTON GROUP
Undifferentiated Pleasanton Group Shale
Traditional Hepler Sandstone
LOST BRANCH FM.
Nuyaka Creek Black Shale
Johnson S-1
T17S R25E Sec.30
Brecheisen #3
T20S R19E Sec.15
Fronk #2
T25S R19E Sec. 28
Payne #9
T27S R15E Sec. 14
Boco #3
T28S R15E Sec. 24
McConnell#4
T34S R15E Sec. 20
?
?
34.5 Miles
32.5 Miles
15.0 Miles
14.0 Miles
35.5 Miles
SCALE:
0
50 Feet
B' (West)
B (East)
HERTHA LIMESTONE
Mound City Black Shale
PLEASANTON GROUP
Undifferentiated Pleasanton Group Shale
Traditional Hepler Sandstone
LOST BRANCH FM.
Nuyaka Creek Black Shale
#1 Moffett
T22S R4E Sec.22
Rees #4
T20S R10E Sec.32
Phillips #1
T20S R15E Sec.33
Brecheisen #3
T20S R19E Sec.15
Knoche #11
T18S R24E Sec. 16
?
36.5 Miles
31.0 Miles
24.5 Miles
26.5 Miles

Figure 9. Cross-sections C-C' and D-D'. Lateral continuity of black shales and Hepler Formation in southern section of study area.


C (North)
C' (South)
HERTHA LIMESTONE
Mound City Black Shale
PLEASANTON GROUP
Undifferentiated Pleasanton Group Shale
Traditional Hepler Sandstone
LOST BRANCH FM.
Nuyaka Creek Black Shale
Van Gundy #1
T19S R12E Sec.2
Rees #4
T20S R10E Sec.32
Hawthorne #1
T25S R10E Sec.1
Land 12-13
T29S R10E Sec.13
McNee #1-A
T32S R10E Sec.2
?
18.5 Miles
24.5 Miles
25.5 Miles
17.8 Miles
SCALE:
0
50 Feet


D' (West)
D (East)
HERTHA LIMESTONE
Mound City Black Shale
PLEASANTON GROUP
Undifferentiated Pleasanton Group Shale
Traditional Hepler Sandstone
LOST BRANCH FM.
Nuyaka Creek Black Shale
Hammer #4
T31S R5E Sec.21
Land 12-13
T29S R10E Sec.13
Russell B-1
T29S R13E Sec.23
Dudley #4
T29S R17E Sec.24
?
36.0 Miles
18.0 Miles
24.2 Miles

based upon sedimentary rock type and dominant sedimentary structures present. The fifth basal lithofacies belongs to the Lost Branch Formation. The four Hepler Formation lithofacies are: 1) quartz sandstone, 2) interstratified siltstone and shale,3) interstratified sandstone, siltstone, and shale, 4) mudstone/coal, and 5) clay shale (Lost Branch Formation). The characteristics of each lithofacies are summarized in Figure 10. Distribution in outcrops and cores are given in measured sections in Appendix A.

Quartz Sandstone Lithofacies

The quartz sandstone lithofacies of the Hepler Formation is characterized by a fine to medium- grained, thinly to thickly bedded sandstone. At the East Pleasanton outcrop section this lithofacies occurs as a massive sandstone approximately 4 meters thick. A small-scale ripple-laminated, slabby sandstone forms the uppermost unit at the Trading Post and Pumpkin Creek sections. Sedimentary structures observed within this lithofacies include a parallel to wavy stratification with occasional small scale cross-stratification (15-20 cm sets). A few isolated vertical burrows were observed at the Southeast Pleasanton outcrop section and are probably *Skolithos* type (Frey and Pemberton, 1989). Mica-rich stratification surfaces are common, as are plant fragments. Most of the sandstone lithofacies is calcareous, containing a "patchy" calcite-cement. An exception to this type of cementation is found at the East Pleasanton section where a tightly-cemented interval up to 0.4m thick contains a poikilotopic calcite cement. The sandstone lithofacies of the Hepler is most commonly overlain and underlain by an interstratified sandstone-siltstone lithofacies that may or may not contain shale. Most of the quartz sandstone lithofacies is described from outcrop exposures. A Gamma-ray well log from the Troike #1 core, the only subsurface example of this lithofacies, indicates a low gamma-ray count that makes a continuous deflection to the left of the 50% sand line and has an upper boundary that returns abruptly the shale base line (Figure 4).

Interstratified Siltstone-Shale Lithofaces

The siltstone- shale lithofacies of the Hepler Formation is characterized by an interstratified siltstone and shale interval that in some places contains lenses of fine-grained sandstone. Within this lithofacies, siltstone is the dominant rock type. It displays stratification that includes lenticular to parallel laminations, wavy bedding and small scale flaser beds. Small scale cross laminae are observed in only a few core samples. A mottled appearance seen locally in some cores is the result of reworking of the sediment through bioturbation. The siltstone is quartz-rich and usually contains a "patchy" calcite cement. Small-scale liquefaction and fluid-loss structures are observed as flame structures, slump structures, and drapes within the cored interval. Most of the unbioturbated shales within the cored interval are thinly laminated. Stratification surfaces are micaceous and plant fragments are observed throughout the lithofacies. The gamma-ray signature for the interstratified siltstone-shale lithofacies forms an irregular pattern just below (to the left) of the shale base line. This lithofacies is observed in all cored wells except Highbaugh, and in all but the Trading Post and Pumpkin Creek surface sections.

Interstratified Sandstone-Siltstone-Shale Lithofacies

This lithofacies consists of interstratified very-fine to fine-grained sandstone, siltstone, and shale. Sandstones within this interval are most commonly thinly bedded (3 to 25 cm). Siltstones and shales when present are thickly laminated to thinly bedded (0.5 to 4 cm). Sedimentary structures include 1) wavy to lenticular beds, 2) wavy laminae, 3) small scale cross-stratification, 4) small scale ripple-laminations, and 5) graded beds that grade from fine-grained to coarser-grained vertically upwards. Some draping of sediments is observed along with a few convoluted beds that are developed by bioturbation of the sediment. Micaceous stratification is common and plant fragments are less commonly observed. Calcite cementation is common. The gamma-ray signature of this lithofacies is characterized as an irregular signature that fluctuates between the shale base line and the 50% sand line. The sandstone-siltstone-shale lithofacies is observed in the Troike, Newland, and Emerson cores and at the Uniontown south, Pumpkin Creek, Prong Creek, Trading Post, East Pleasanton, and Southeast Pleasanton sections.

Mudstone/Coal lithofacies

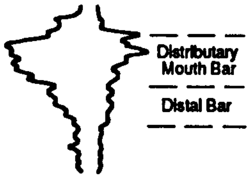
The Mudstone/coal lithofacies consists of a gray blocky mudstone that is usually but not always overlain by a coal. Laminae rarely appear near the base of the mudstone. Plant fragments are common and rare burrowing is observed. Intervals of mudstone within core and surface sections of this lithofacies are calcareous. Root structures are occasionally observed. This lithofacies is usually micaceous, and pyrite is commonly associated with the carbonaceous material present. The uppermost intervals of the mudstone show an increase in the occurrence of organic material, and coal stringers are observed.

The coals associated with this lithofacies are usually fissile and commonly exhibit calcite fracture fills. Coal thickness varies from 5 cm. to 30 cm. The mudstone/coal lithofacies is described from both core (Newland, Gaddy, Highbaugh, and Emerson) and outcrop exposures (Uniontown east and Pumpkin Creek). The gamma-ray log signature for the above mentioned lithofacies is characterized by an irregular high gamma-ray count that occurs near the shale base line. The coals are recognized by the combination of low gamma-ray and neutron peaks.

Clay Shale

The clay shale lithofacies observed in core and surface section is a thinly laminated clay shale at the base and grades upward through the interval into an interlaminated silty shale. Small-scale, cross-laminated siltstone occurs at the top of the interval. This lithofacies composes the upper portion of the Lost Branch Formation. An increase in mica-rich and carbonaceous-rich strata are recorded towards the top of the interval. This lithofacies is sparsely fossiliferous with scattered crinoid and brach debris and contains scattered isolated burrows. Ironstone concretions are found throughout this interval at the Trading Post surface section. The clay shale lithofacies is in abrupt contact with the underlying black shale and usually in gradational contact with the overlying interstratified siltstone-shale lithofacies. The gamma-ray signature of the clay shale lithofacies is irregular and plots slightly below (to the left of) the shale base line (See Figure 4).

Figure 10. Characteristics of each lithofacies. Based on outcrop and core material, supplemented with typical gamma-ray and neutron log signatures.

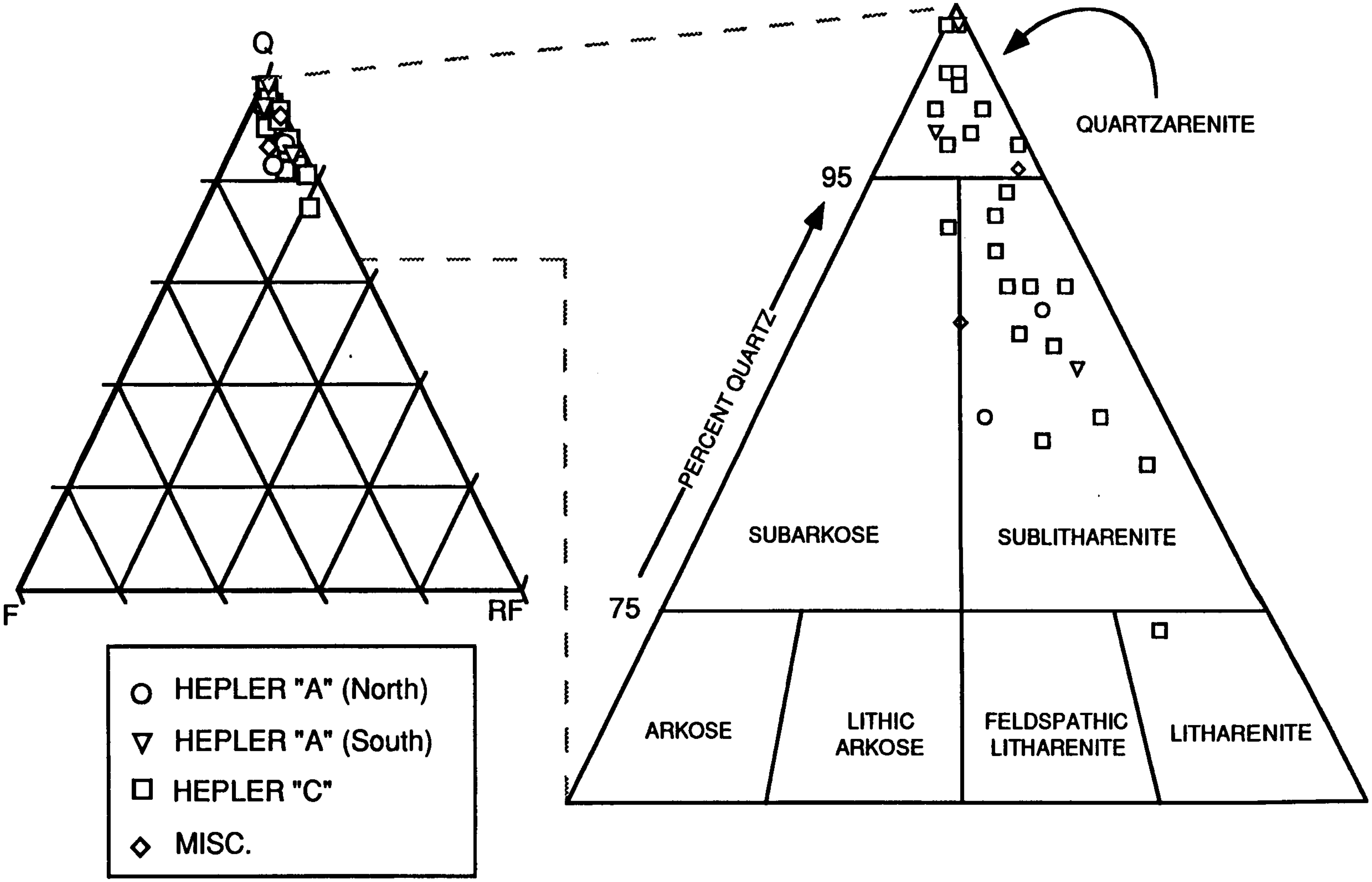
HEPLER FORMATION LITHOFACIES					
LITHOLOFACIES	Sandstone very fine-to-med-grained	Interstratified siltstone and shale	Interstratified sandstone, siltstone and shale	Mudstone Coal	Clay Shale (Lost Branch Fm)
STRATIFICATION	Thinly to thickly bedded; Wavy stratification some cross-stratification	Lenticular laminae to thin wavy beds; minor small scale cross-laminae	Convoluted; small scale cross and rippled-laminae; flaser beds; graded beds	Blocky; occasionally lamimae near base	Thin laminae; minor cross-stratification
BIOGENIC STRUCTURES	Isolated vertical burrows; *Skolithos*	Localized intense bioturbation "mottled appearance"	Isolated horizontal burrows	Isolated burrows	Isolated burrows; sparsely fossiliferous (crinoids & brachs)
OTHER ASSOCIATED CONSTITUENTS	Micaceous; plant fragments; calcareous	Micaceous stratification surfaces; "patchy" calcite cementation; carbonaceous debris	Micaceous stratification surfaces; occasional plant fragments; frequently calcareous	Micaceous; Fissile coal with calcite fracture-fills; pyrite	Micaceous stratification; plant fragments; calcareous; pyrite
TYPICAL GAMMA-NEUTRON LOG SIGNATURE					

PETROGRAPHIC ANALYSIS

Thirty-three thin sections representing 3 different sandstone stratigraphic horizons near the Desmoinesian-Missourian boundary in southeastern Kansas were examined. Of the 33 thin sections, 9 were from 4 cores and 24 were from outcrop exposures. Hepler "C" (Sutton, 1985) , the uppermost and traditionally reguarded stratigraphic position of the Hepler sandstone, is represented by samples from all core and the following outcrop thin sections: Pumpkin Creek (PuC); Trading Post (TP); East Pleasanton (EP); Southeast Pleasanton (SEP); and the upper Prong Creek (PC) sections. Hepler "B", a lower interval of sandstone is now known to be represented only by thin bedded shaly sandstones above the Idenbro Limestone at Uniontown East (UE) which were not collected. Hepler "A", the lowest of the 3 sandstone horizons, is represented by samples from both lower Prong Creek (PC) and the Uniontown East (UE) section. Petrographic examination of all three sandstone bodies was undertaken to see if there is any petrographic criteria to distinguish one sandstone body from another. The importance of this is that any sandstone near the Desmoinesian-Missourian border in southeastern Kansas has been traditionally considered Hepler (See Stratigraphy Section).

Using Folk's (1974) classification scheme: Samples analyzed from Hepler"C" sandstones are quartz arenites, sublitharenites and litharenites. The 5 samples of Hepler "A" sandstones are arenites andsublitharenites (figure 11).

Figure 11. Classification of three sandstone horizons sampled in the study area located in southeastern Kansas. Hepler "C" samples are from the traditional Hepler stratigraphic horizon.


Q
F
RF
○ HEPLER "A" (North)
▽ HEPLER "A" (South)
☐ HEPLER "C"
◇ MISC.
QUARTZARENITE
95
PERCENT QUARTZ
75
SUBARKOSE
SUBLITHARENITE
ARKOSE
LITHIC ARKOSE
FELDSPATHIC LITHARENITE
LITHARENITE

[redacted]

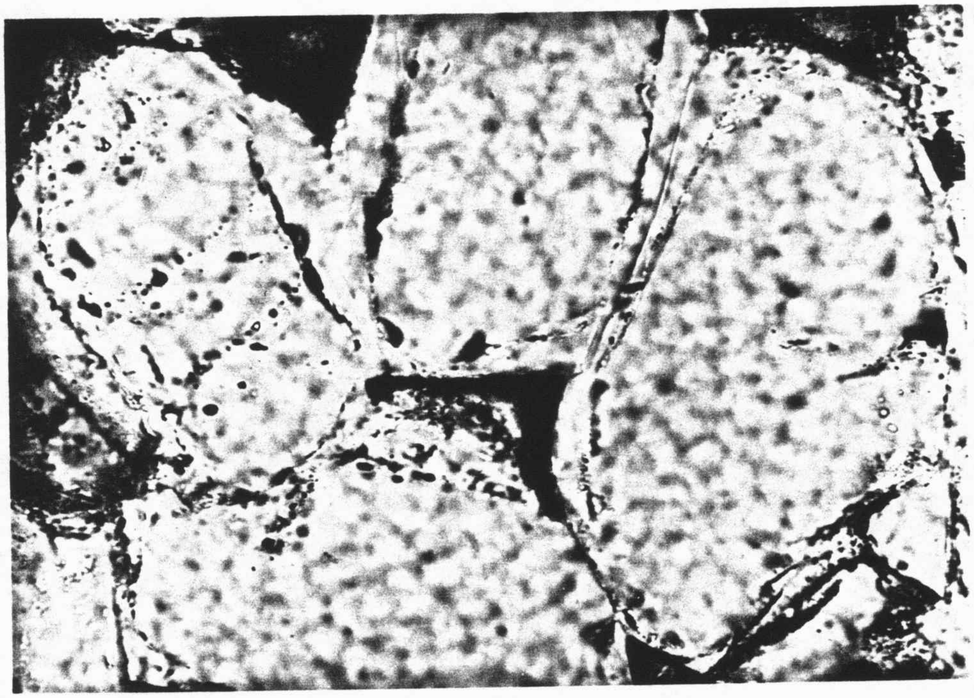
Several samples contain over 10% matrix classifying them as wackes according to Dott (1964).The siliciclastic components of the 3 sandstones bodies include: monocrystalline and polcrystalline quartz; orthoclase; plagioclase; muscovite; bioltite; chlorite; glauconite; rutile; tourmaline; and rock fragments. Authigenic minerals include: calcite; silica; iron oxide; and clays (kaolinite and chlorite). Little secondary porosity (1-3%) was observed in several samples due to the tight cementation of the sandstones.

Detrital Minerals

Monocrystalline Quartz

Monocrystalline quartz is the most abundant mineral in the sandstones sampled and analyzed. Monocrystalline quartz averages 52.7 percent of Hepler "C" bulk rock composition. Quartz grain size ranges from very fine sand (0.07 mm) to medium sand (0.35 mm) at the maximum grain diameter measured in thin section. Medium sand-sized quartz grains were observed only in the Troike #1 (TR) core. Grain size increases upward throughout the stratigraphic sections. Monocrystalline quartz grain shape varies in the Hepler. Most commonly quartz grains are subangular followed by angular grains to subrounded grains in order of their abundance. Partial percentages of angular quartz grains can be attributed to authigenic silica cement forming around subrounded, low spherocity quartz nuclei. Quartz overgrowths are recognized by observation of "ghost" rims between the quartz nuclei and silica cement (Figure 12). Minor amounts of inclusions were observed in the quartz grains in the form of vacuoles and rutile needles. Hepler "C" quartz grain extinction characteristics (Folk 1974) include: substantial single grain, slightly undulose extinction and predominant single grain

Figure 12. Photomicrograph showing concavo-convex quartz grain contact. "Ghost" rim are visible between overgrowth and original quartz nuclei (arrows). Reduction in porosity occured as original pore space was infilled with silica cement. Plane light. East Pleasanton outcop sample.



straight (unit) extinction. This would indicate shallow burial with minimal effects of lithostatic pressures and temperatures. Extinction angles ranged between 1 and 10 degrees. Etched grains were common with minor amounts of embayments.

Polycrystalline Quartz

Polycrystalline quartz abundance ranges between 0.8 and 4.8 percent with an average of 2.7 percent volume of the bulk rock, and from coarse silt (0.04 mm) to fine sand (0.175 mm) in grain size. Grain shape varied from subangular to subrounded with low sphericity. Individual quartz grains within the composite grain manifested straight (unit) to slightly undulose extinction patterns, which indicates only shallow burial, resulting in limited observation of plastic deformation features. Both igneous and metamorphic composite grains were present. Igneous polycrystalline quartz grains consist of equant crystals with little or no intercrystalline suturing composing the composite grain. Metamorphic polycrystalline quartz was distinguished by the presence of a large number of stretched and elongate, highly sutured crystals.

Feldspars

Both plagioclase and orthoclase feldspar combined, comprise from 0 to 6.6 percent volume of the bulk rock. Hepler "C" feldspar averages 1.3 percent of bulk rock volume. Trace amounts of both microcline and perthite were identified by their twinning patterns. Plagioclase was the most abundant feldspars observed. Grain sizes for all feldspars ranges from coarse silt (0.05 mm) to the lower boundary of medium sand (0.25 mm). The coarser-grained feldspars were observed in the medium-grained sandstone of the Troike core (Hepler "C"). Grain shape is angular to subangular and sphericity is low. Most of the plagioclase feldspar grains are flakes and exhibit alteration and dissolution features including sericitization and kaolinization. Using the Michel-Levy method, plagioclase feldspar is of albite composition with extinction angle measurements between 13 and 19 degrees. Total feldspar percentages in the Hepler "C" sandstone ranged from 0 to 4.8 percent. Hepler "A" percentages ranged from 0 to 6.6 percent with more feldspathic samples in the north (Uniontown East)..

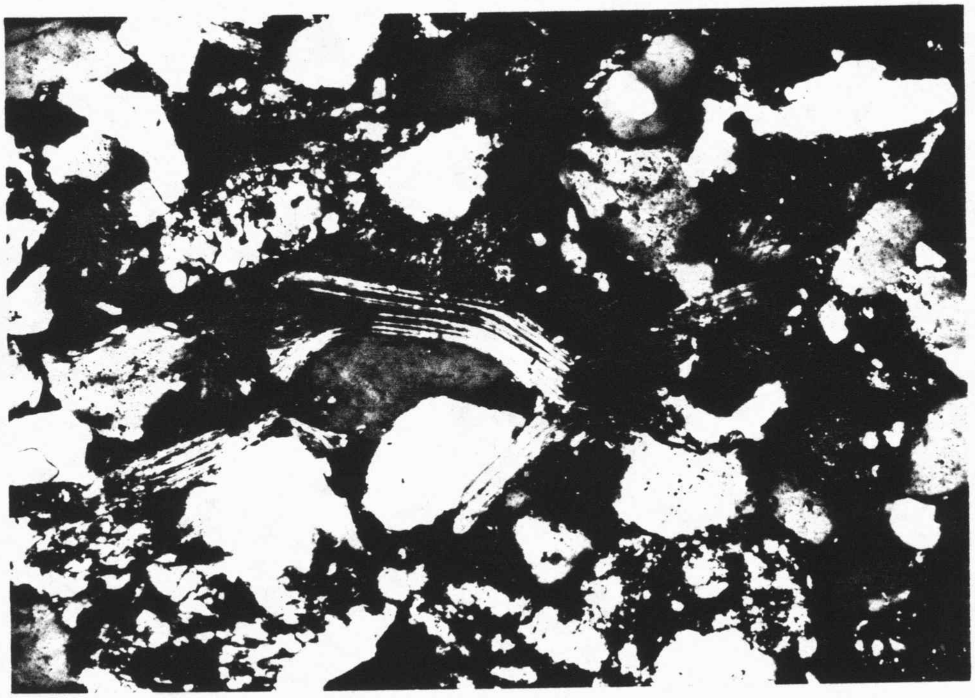
Muscovite

Muscovite is the predominant mica observed and volumetrically makes up from trace amounts to 8.0 percent of the bulk rock composition. Average Hepler "C" composition is 2.6 percent. Muscovite is recognized as elongate colorless laths. Grain size ranges from coarse silt (0.05 mm) to medium sand (0.4 mm). Muscovite grains follow a roughly parallel orientation to stratification. Mechanical compaction is observed as bending and fracturing of muscovite grains around other detrital grains (Figure 13). In all 3 sandstone bodies, muscovite abundance decreases upward through the stratigraphic section. An abundance of muscovite indicates a possible metamorphic source (Blatt, 1982). Hepler "A" sandstones in the south (lower Prong Creek section) are more muscovite rich than are Hepler "C" or Hepler "A" to the north.

Biotite

Biotite is observed in thin section as brown, pleochroic laths that comprise from trace amounts to 5.6 percent of the bulk rock examined. Average

Figure 13. Photomicrograph showing elongate muscovite grains (m) in polarized light. Grain bending and wedging are due to mechanical compaction. Grain above and to the left of wedged muscovite is polycrystalline quartz. Pumpkin Creek outcrop (PC).



composition of Hepler "C" samples is 1.1 percent. Grain size ranges from coarse silt (0.05 mm) to medium sand (0.4 mm). Biotite displays the same nearly bed-parallel grain orientation and mechanical compaction characteristics as muscovite. Hepler "C" sandstones in cores are biotite rich compared to outcrop samples. This is probably reflects the weathering of biotite to clays and iron oxide on exposed sections.

Chlorite

Chlorite, recognized as pale green pleochroic laths, comprises up to 2.4 percent of bulk rock volume. Hepler "C" chlorite abundance averages 0.6 percent. Grain size ranges from coarse silt (0.05 mm) to fine sand (0.2 mm). Chlorite in the Hepler "C" sandstone may have originated either as an alteration product of biotite or from a low grade metamorphic source. Chlorite abundance decreases upwards throughout the stratigraphic sections in all sandstone bodies. In the Hepler "C", sandstone chlorite is less abundant in outcrop than in core samples, possibly due to instability under surface conditions of modern weathering.

Glauconite

Glauconite is observed in thin section as high-birefringent, "grainy" microcrystalline pellets. Glauconite makes up trace amounts of the bulk rock volume of Hepler "C" sediments when present. Grain size ranges from very fine sand (0.075 mm) to fine sand (0.2 mm). Pellet shape is subrounded to rounded with high sphericity. Glauconite occurs only in Hepler "C" core samples and is absent in all three sample sets from outcrops of sandstone bodies.

Rock Fragments

Rock fragments include sedimentary siltstone, shale and chert and schistose metamorphic fragments. These fragments compose up to 16 percent of bulk rock volume. Hepler "C" sediments average 8.1 percent rock fragment composition. This component is responsible for the greatest variation in QFL spacing. The Hepler "C" sandstone classification range from quartz arenites, through sublitharenites, to litharenites (Figure 11) is primarily influenced by the percentage of rock fragments present.

Schistose metamorphic fragments (Figure 14) are the most abundant and constitute up to 14.4 percent of bulk rock volume. Fragment size ranges up to fine sand (0.2 mm) and shape from subangular to subrounded. Within the fragment, micas are in subparallel to parallel alignment.

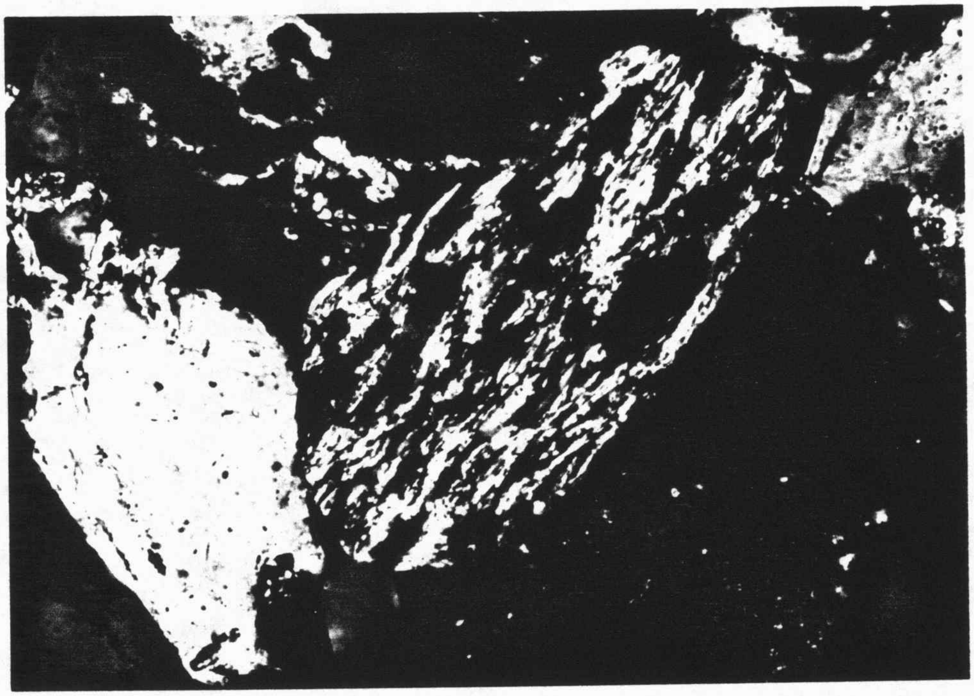
Sedimentary rock fragments (siltstone and rare shale) range in size from fine sand (0.2 mm) to medium sand (0.4 mm). Fragment shape is angular to subangular and sphericity is low. Chert grain size ranges from very fine sand (0.1 mm) to fine sand (0.2 mm). Grain shape is subangular to subrounded and has low sphericity. Chert composes up to 4.0 percent of bulk rock volume.

Authigenic Components

Authigenic components recognized in thin section include: quartz, calcite, iron-oxide, and clays.

Silica cement takes the form of quartz overgrowths and composes up to 6.4 percent of the bulk rock volume. Calcite is the predominant void filling cement. It volumetrically composes up to 45.6 percent of the rock. Clays recognized in thin-section include both kaolinite and chlorite. Fe-oxide, a pore filling cement, composes up to 20.4 percent of the bulk rock volume. Since Fe-

Figure 14. Photomicrograph of metamorphic rock fragment under crossed polarizers. Sample Tr 127'3".



oxide is found only in outcrop thin sections, it could be considered as a modern weathering product. The source of the iron can be from leaching of the overlying soil, or from the degradation of iron-bearing minerals such as biotite and chlorite upon subareal exposure.

Discussion

Hepler"A" sandstones, from the north (Uniontown East) are mineralogicaly similar to one another and plot as quartz-rich sublitharenites (Figure 11). These samples are fine grained, poorly sorted and texturally submature (Folk 1951). Textural maturity is based upon sorting, rounding of grains, and amounts of clay matrix material. Hepler "A" sandstone samples are compositionally mature with an abundance of quartz and scarcity of feldspars. Porosity is low but increases up to 17.6% towards the top of the section. Porosity appears to be mostly secondary, having been enhanced by calcite and feldspar dissolution. Fe-oxide concentrations appear to be a modern weathering characteristic. Minor pressure solution (Adams, 1964), is indicated by large amounts of long and tangential grain contacts and moderate calcite cementation. The average contact index (number of grain to grain contacts with a specific grain) is 2.1.

Hepler "A" sandstones from the south (lower Prong Creek) plot as quartz arenites and sublitharenites dependent upon the percentage of rock fragments present (Figure 11). The Hepler "A" sandstone samples analyzed indicate a lack of textural maturity. Using Folk (1951), the specimens are submature based upon: angular to subangular grains; poor sorting; and minor clay component. The sandstone is compositionally mature with an abundance of quartz to feldspar components. Mica concentration decreases while rock fragment percentages increase towards the top of the section. Minor pressure solution features (Adams, 1964) include: original grain outlines, predominantly long and tangential grain contacts, and poor cementation (calcite, Fe-oxide). This could possibly indicate shallow burial. Porosity is low throughout the section. The contact index for the Prong Creek section ranges from 1.8 (PC 1.3) to 3.2 (PC 4.3) from the base of the section the top.

Hepler "C" sandstones are the most compositionally diverse of the three sandstone bodies, plotting as quartz arenites, sublitharenites, and litharenites (Figure 10). Variations in quartz grain and rock fragment percentages account for this diversity. Hepler "C" sandstones are texturally submature (Folk, 1951) as defined by their poor to moderate sorting, subangular grains, and minor spotty clay component. In well-cemented units the contact index is a low 1.8 (EP 0.9 and EP 1.5). With dissolution of cement the contact index increases to 3.5 (PuC samples). Average packing density, the length of grains intercepted divided by the length of the traverse multiplied by 100 (Kahn, 1956), for the Hepler "C" sandstones is approximately 42 percent. Packing proximity, the number of grain to grain contacts divided by the total number of contacts of all kinds (grain to matrix and grain to cement) multiplied by 100 (Kahn, 1956), ranges from 21 percent to 54 percent. Contacts encountered along the line of traverse were predominantly long and tangential with occasional concavo-convex shape, indicating moderate pressure solution (Adams,1964). In both packing density and packing proximity, mica-rich and schistose fragment dominated samples plotted near the upper end of the range. In one sample (EP unit 4) , "floating grains" in a poikilolitic calcite cement, had the lowest values for both parameters.

This may indicate maintence of grain separation by early cemention during early burial. Blatt (1982) suggested that packing density and packing proximity determinations depend not only on burial depth (compaction), but on the depth at which cement may have precipitated and on the mineral and lithic fragment composition of the rock.

Petrographically, there is little difference between the two sandstone bodies identified as Hepler in southeastern Kansas. Compositional, textural, and fabric characteristic differences are so minor and plot within the same field (Figure11), that it would be difficult to distinguish each horizon petrographically.

DEPOSITIONAL ENVIRONMENTS

The depositional environment of the Hepler Formation was interpreted by using the following: 1) Regional thickness variations as indicated by the isopach thickness maps of the intervals between the Nuyaka Creek black shale bed (Lost Branch Formation) and the Mound City black shale (base of the Hertha Limestone) and between the Nuyaka Creek black shale and the top of the traditionally recognized Hepler sandstone. This sandstone unit is overlain by the Exline Limestone to the north and the South Mound shale to the south; 2) Sandstone isolith map construction for the study interval; 3) Geometry of the Hepler formation as illustrated in cross-section; 4) Vertical and lateral variations in lithologic composition, sedimentary structures, and depositional sequence of described lithofacies from cores and outcrop samples and 5) lithologic interpretation of well log signatures. Five deltaic system environments recognized by lithofacies description include: 1) prodeltaic (upper part of Lost Branch Formation); 2) distal bar; 3) distributary mouth bar; 4) bay fill or crevasse splay; and 5) marsh/swamp (Figure 15).

Depositional Interpretations

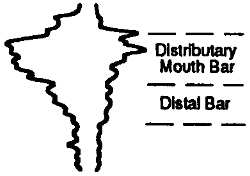
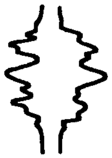
Regional Thickness Variations

Two isopach maps (Figures 5 and 6) were constructed for the Hepler Formation in southeastern Kansas using thicknesses obtained from well log and

Figure 15. Summary of lithofacies characteristics and interpreted depositional environments.

[redacted]

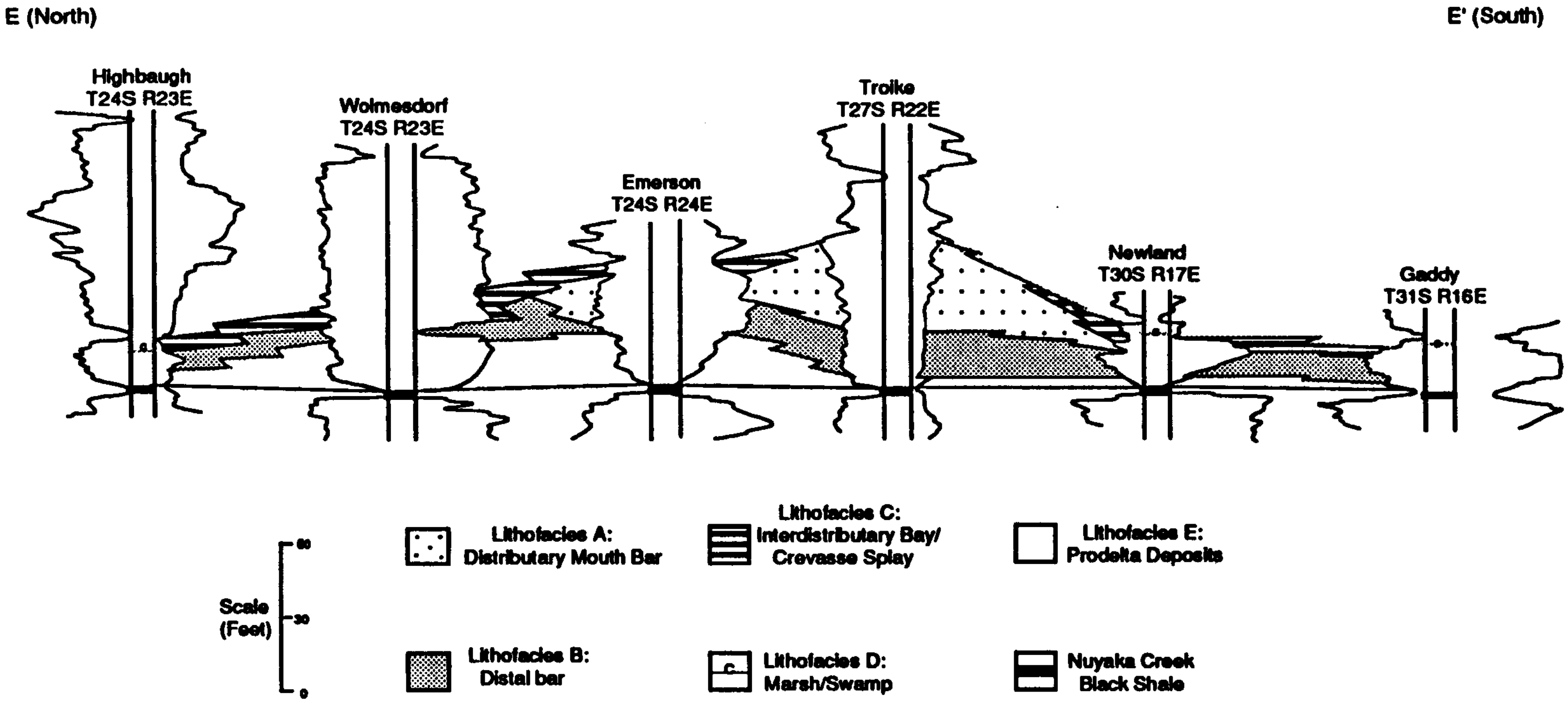
HEPLER FORMATION LITHOFACIES

LITHOLOFACIES	Sandstone very fine-to-med-grained	Interstratified siltstone and shale	Interstratified sandstone, siltstone and shale	Mudstone Coal	Clay Shale (Lost Branch Fm)
STRATIFICATION	Thinly to thickly bedded; Wavy stratification some cross-stratification	Lenticular laminae to thin wavy beds; minor small scale cross-laminae	Convoluted; small scale cross and rippled-laminae; flaser beds; graded beds	Blocky; occasionally lamimae near base	Thin laminae; minor cross-stratification
BIOGENIC STRUCTURES	Isolated vertical burrows; *Skolithos*	Localized intense bioturbation "mottled appearance"	Isolated horizontal burrows	Isolated burrows	Isolated burrows; sparsely fossiliferous (crinoids & brachs)
OTHER ASSOCIATED CONSTITUENTS	Micaceous; plant fragments; calcareous	Micaceous stratification surfaces; "patchy" calcite cementation; carbonaceous debris	Micaceous stratification surfaces; occasional plant fragments; frequently calcareous	Micaceous; Fissile coal with calcite fracture-fills; pyrite	Micaceous stratification; plant fragments; calcareous; pyrite
TYPICAL GAMMA-NEUTRON LOG SIGNATURE					
DEPOSITIONAL ENVIRONMENT	Distributary Mouth Bar	Distal Bar (Delta Front)	Bay Fill & Crevasse Splay	Marsh/Swamp	Prodelta

core observations. The isopach maps provide a distribution and overall geometry for the depositional setting of the Hepler, and indicate paleosource directions for the siliciclastic sediments of the Hepler.

The Hepler Formation is interpreted to have been deposited in a fluvial-dominated deltaic system. This interpretation is based upon both isopach maps that indicate a thinning of sediments from east to west, the development of lobate geometries, and the sandstone isolith map that indicates the presence of several channels that extend out of the outcrop belt and traverse across the shelf, forming and extending through time the lobes of the deltaic system. These channels also may be indications of later developing fluvial system that incise the delta complex. The western edge of Hepler sediments represents the farthest transportation and deposition of fine-grained material. This east-west progradation of the delta system in the study area occurred with the Lost Branch regression when the inland sea withdrew from the Cherokee Shelf (Heckel, 1991). The lobate geometry and apparent lack of coastal barriers would indicate a highly constructive deltaic system (Fisher et. al., 1969). Fluvial processes causing rapid seaward progradation were probably aided by weak wave energy, weak tidal currents, and low littoral drift to give the Hepler its elongate lobate geometry (Coleman and Wright, 1975). The two large lobes, one in the north and another in a southern location within the study area as indicated by the Nuyaka Creek-traditional Hepler isopach map (Figure 6) are separated by an area of low sediment accumulation which maybe attributed to the influence of the Bourbon Arch in the subsurface. Cross-section E-E' (Figure 16) constructed from a transect of cores across Montgomery, Wilson, and Bourbon counties in

Figure 16. Cross-sedtion E-E'. Transect of cores and their well-log signatures in southeastern Kansas. Cores provided a framework for lithofacies description and depositional environment interpretation. Nuyaka Creek black shale used as datum.



E (North)
E' (South)
Highbaugh
T24S R23E
Wolmesdorf
T24S R23E
Emerson
T24S R24E
Troike
T27S R22E
Newland
T30S R17E
Gaddy
T31S R16E
Scale
(Feet)
60
30
0
Lithofacies A:
Distributary Mouth Bar
Lithofacies B:
Distal bar
Lithofacies C:
Interdistributary Bay/
Crevasse Splay
Lithofacies D:
Marsh/Swamp
Lithofacies E:
Prodelta Deposits
Nuyaka Creek
Black Shale

southeastern Kansas, shows sediment morphologies that (when coupled with lithofacies descriptions and well-log interpretations) are interpreted to represent prodelta muds, distal bar, distributary mouth bar, and bay-fill/crevasse-splay deposits in a fluvially-dominated deltaic setting.

The Hepler sandstone isolith map (Figure 9) shows several elongate sandbodies that represent distributary/fluvial channels in both the northern and southern lobes. Thickness variations within the lobes range from 10 feet (3.0m) to 40 feet (12.1m) in a matter of a few miles (< 8 km). These features probably represent fluvial systems that followed the distributary channels across the shelf as the seas abandoned the shelf area during the late Lost Branch and Hepler regression.

Cross-sections A-A' and C-C' (Figures 8 and 9) show sheet-like morphology of Hepler sediments. These cross sections indicate little variability in traditional Hepler interval thickness from north to south. Most thickness variation between the two black shale marker beds occurs within the overlying undifferentiated upper Pleasanton Group shales. A pronounced thinning of upper Pleasanton Group sediments is observed towards the south. Cross sections B-B' and D-D' were constructed along channel-shaped sediment thicks in both the northern and southern lobes respectively. Both indicate a general thinning of Hepler sediments to the west. This implies progradation of siliciclastic sediments from east to west.

Paleosource directions for siliciclastic sediments of the Hepler Formation are from the northeast, southeast, or both, as indicated by the westerly sediment thickening shown on the isopach maps and channel direction on the sandstone isolith map. Possible sediment dispersal centers for the northeast would include the Canadian Shield (cratonic) and northern Appalachians (Potter and Pryor, 1961). Southeastern siliciclastic sources would have been the Ouachita foldbelt. To the east the Ozark Uplift, a low positive relief area, may have been a minor clastic source (Rascoe and Adler, 1983). But due to the low percentages of chert found in Hepler sediments, which would be expected to be high from the Mississipian cherty limestones that were probably exposed around the Ozarks during the Missourian, this area cannot be considered as a major source of siliciclastic sediments for the Hepler.

Lithofacies and Deltaic Environments

Prodelta Deposits

Laterally continuous deposits of interlaminated clays and fine silts of lithofacies E are interpreted as representing prodelta deposits forming the basal portion of a prograding delta. The prodelta environment is the most distal and subaqueous regime of a delta. These fine-grained sediments were deposited as fresh water, sediment-laden effluent plumes extended and expanded into the waters of the retreating sea on the shelf. As the plume extended away from the distributary and dispersed, a velocity decrease allowed only fine-grained sediment to be held in suspension within the water column (hydrologic sorting). Further extension of the effluent plume into the basin saw the deposition of the fine-grained sediment from suspension as prodeltaic muds. Prodeltaic deposits within the study area from the upper part of the Lost Branch Formation, and are overlain by coarser sediments of the Hepler Formation.

Prodeltaic deposits of the Lost Branch Formation in southeastern Kansas show little lithologic variation. Study of core samples and outcrop show that the prodeltaic sediments in the Lost Branch Formation include thinly-laminated (<3mm.) clay shale to interlaminated clay shales and silts. The primary sedimentary structure observed is parallel laminations. A few starved siltstone ripples are observed in the upper part of the deposit. Occasional localized discordant laminae are the result of burrowing in the substrate by sediment feeders. Rapid sedimentation within the facies suppressed homogenization of the laminae through bioturbation. The Lost Branch Formation represented in the Wolelsdorf #1, Highbaugh #1, Emerson #1 cores is sparsely fossiliferous, containing scattered brachiopod and crinoid debris.

Prodeltaic deposits in southeastern Kansas are micaceous and contain organic matter. The presence of carbonized plant fragments may represent periods of flooding when terrestrial material was dispersed into the prodelta environment. Incomplete oxygenation and plant breakdown were probably a result of by a decrease in oxygen caused by partial decay of organic material. Color alterations in prodelta deposits were caused by varying degrees of organic content and/or alterations of fine-grained silts and clays (Figure 15).

In all cores and the Trading Post and Pumpkin Creek sections, the Nuyaka Creek black shale is overlain by units containing regressive prodeltaic deposits. The rapid influx of siliciclastic material shut off carbonate production, thereby explaining the absence of an upper regressive limestone that typically occurs above the maximum highstand black shale unit in most Kansas cyclothems.

Delta Front Deposits

The delta front facies within the Hepler Formation in southeastern Kansas includes both distal bar and distributary-mouth bar deposits. These sediments are in gradational contact landward with the underlying prodelta deposits and are recognized as the seaward-sloping margin of an advancing delta sequence (Coleman and Prior, 1982). Delta-front sediment deposition occurred distally to the advancing delta as shoaling conditions were reached with decreasing fluvial velocity and reduced river competence. Distal bar sediments are finer-grained than distributary-mouth sediments and were winnowed from the sediment package out on the shelf. The resulting delta-front facies of the Hepler is therefore recognized as a coarsening-upward sequence that includes mostly laminated (< 5 mm.) to thinly bedded (< 3 cm.) siltstones and shaley siltstones that grade upward into lenticular, rippled, and cross-stratified siltstones and medium to massive bedded fine-grained sandstones (Figure 16).

Distal Bar Deposits

Distal bar deposits of the Hepler Formation are siltstone dominated but highly variable and are represented by the interstratified siltstone and shale facies. They consist of laminated to thinly bedded silts, sands, and clays. The intercalated sediments resulted from changes in wave and current energy conditions. Bedding thickness (2-3 cm.) increases towards the top of the interval. Variability within the interval is probably due to sedimentation by multiple distributary systems where discharge was not equally divided and by the wax and wane of individual distributaries and their lateral migration (Elliott, 1986). This is observed in the lower portion of the Hepler Formation at Trading Post on the Marais des Cygnes River

Figure 17. Photograph of delta front deposits in core. Note gradational change from siltstone/shale dominated lithology of distal bar deposits to sandstone dominated lithology of distributary mouth bar deposits from right to left in the photograph. Photo of Troike #1 core interval 110'2" to 139'.


TOP
GS
TROIKE #1
0'2' - 139'

where thinly bedded shaley sandstones dominate compared to stratification characteristics displayed in theTroike #1 and Emerson #1 cores where interlaminated silts and shales dominate.

Distal bar laminae are mottled and disrupted near the base of the interval. This indicates bioturbation, which is confirmed by the presence of burrows in cores and outcrops and bedding-parallel trace fossils observed on shale beds at the Southeastern Pleasanton outcrop location. Fluid release structures are observed in the Troike core and indicate differential compaction between sediment types. Sedimentary structures in the distal bar facies include flaser bedding, starved ripples and wavy irregular bedforms, all indicating shifting energy conditions. Banding observed in the lower distal bar deposits are due to variations in grain size caused by fluctuations in suspended sediment supply. Small scale slumps and drapes, seen only in the Troike core, developed as a result of rapid sediment influx overloading previously deposited water laden sediment. River transported plant debris found within the interstratified siltstone-shale lithofacies is the result of periodic floods that deposited the material in the distal bar environment. Both outcrop exposure and core indicate the transition from an argillaceous to an arenaceous dominated environment.

The gamma-ray signature of distal bar deposits (Figure 14; quartz sandstone and interstratified siltstone-shale lithofacies) in the study area is a coarsening upward signature that grades into distributary mouth bar sandstones (low gamma-ray count) or bay fill/crevasse splay deposits (high gamma-ray counts) dependent upon the well log distance from from the distributary. Distal bar deposits are laterally continuous and observed in all cores (Figure 16).

Distributary Mouth Bar

Distributary mouth bar deposits in the Hepler Formation are fine-grained to medium-grained, thin to thickly bedded sandstone dominated and show little evidence of bioturbation due to high rates of siliciclastic sediment influx. Quartz sandstone lithofacies most likely represents deposition in this type of environment. Scrunton (1960) indicated distributary mouth bar deposition as a shoaling process that implies a decrease in velocity and reduction in effluent competence as it leaves the channel. Bedding thickness increases to approximately 1 m near the top of the sequence at the East Peasanton exposure. Sandstones deposited within this facies are moderately to well sorted and clean due to winnowing of the sediment by wave processes.

Sedimentary structures include: A) ripple laminations, B) flaser beds, C) small scale cross beds, D) trough cross-stratification and E) planar cross-stratification. Most of the structures were produced by high rates of sediment transport and deposition by traction currents at the distributary mouth during flooding events. At the East Pleasanton section, fine-grained interstratified sandstone and shales with micaceous ripple-laminations (0.5 to 2.0 cm.) and large plant fragments are observed overlying a massive coarse-grained sandstone. The massive nature of the deposit indicates bed load transport of sediment by water in a distributary channel. The large plant fragments indicate deposition proximal to the source area (swamps and marshes). This possible channel-fill deposit is cross-stratified and includes numerous clay-shale partings. The overlying fine material dropped out of suspension over the channel deposit at low water stage. The sandstone isolith map (Figure 7) shows that the sandstones of the Hepler Formation have a lobate geometry in the east and are more elongate towards the western margins of the map area. This would suggest a possible series of channel abandonment.

The gamma-ray signature characteristic of the distributary mouth bar sandstones forms the upper portion of an overall coarsening upward signature that is characteristic of the delta front environment. The gamma-ray curve in this interval is deflected to left of the 50% sand line. Distributary mouth bar deposits are usually in gradational contact with the underlying distal bar sediments (Figure 15).

Distributary mouth bar deposits are recognized only in the Troike (Tr) and Emerson (Em) cores and the east Pleasanton (EP) outcrop locations.

Bay-fill and Crevasse-splay Deposits

Crevasse-splay and bay-fill deposits occur when breaks in the levees of main distributary channels during times of repeated flooding, result in infilling of interdistributary bays on the lower delta plain (Coleman and Prior, 1982). Bay-fill deposits of the Hepler delta complex consist of interlaminated (<5 mm.) clayey mudstones and silty clays that grade vertically into interlaminated shales and silts, with the uppermost beds being siltstone dominated. Thinly bedded fine-grained sandstones and sandstone lenses are also associated with this deposit. Burrowing is common in the mudstone units of the Emerson #1, Womelsdorf #1, Newland #1 and Gaddy #1 cores. The base of these units are mottled, due to heavy bioturbation that destroyed laminae. Bioturbation decreases upwards towards the top of the unit as a result of increased sediment accumulation rates. Small scale ripple and wavy laminations were produced by currents in a shallowing interdistributary bay with sediment buildup. Continued sediment influx created a coarsening upward sequence of alternating clays, silts and fine-grained sands.

Crevasse splay and bay fill deposits have variable gamma-ray log signatures that are dependent upon both the type and thickness of the sediment. In most cases a series of stacked coarsening upwards signatures are observed where several crevasse-splays through time.

Marsh/Swamp Deposits

Blocky mudstones and overlying coal deposits are interpreted as developing in a marsh or swamp environment. Coleman and Prior (1982), indicated that in modern deltas, widespread swamps and marshes develop across the delta plain in a poorly drained environment only a few feet above sea level. These areas are heavily vegetated and explain the high organic content of the sediments.

In cross-section E-E', thin coals are found in the Highbaugh #1 (11 inch, 0.28m), Newland #1 (6 inch, 0.15 m), and Gaddy #1 (3 inch, 0.08 cm.) cores. The Pumpkin Creek section basal coal is approximately 0.4 meters thick and the Uniontown south section has a 0.09 m coal in the Hepler interval. All coals are underlain by a variable thickness of underclay containing rooted plant material. These coals represent aggraded bay-fill or crevasse-splay deposits above sea level and likely develop *in situ* as evidenced by the root structures in the underlying mudstones. Pyrite replacement of plant material observed in core within these deposits was due to the anoxic bottom conditions with hydrogen sulfide production as suggested for similar Holocene deposits by Coleman (1966).

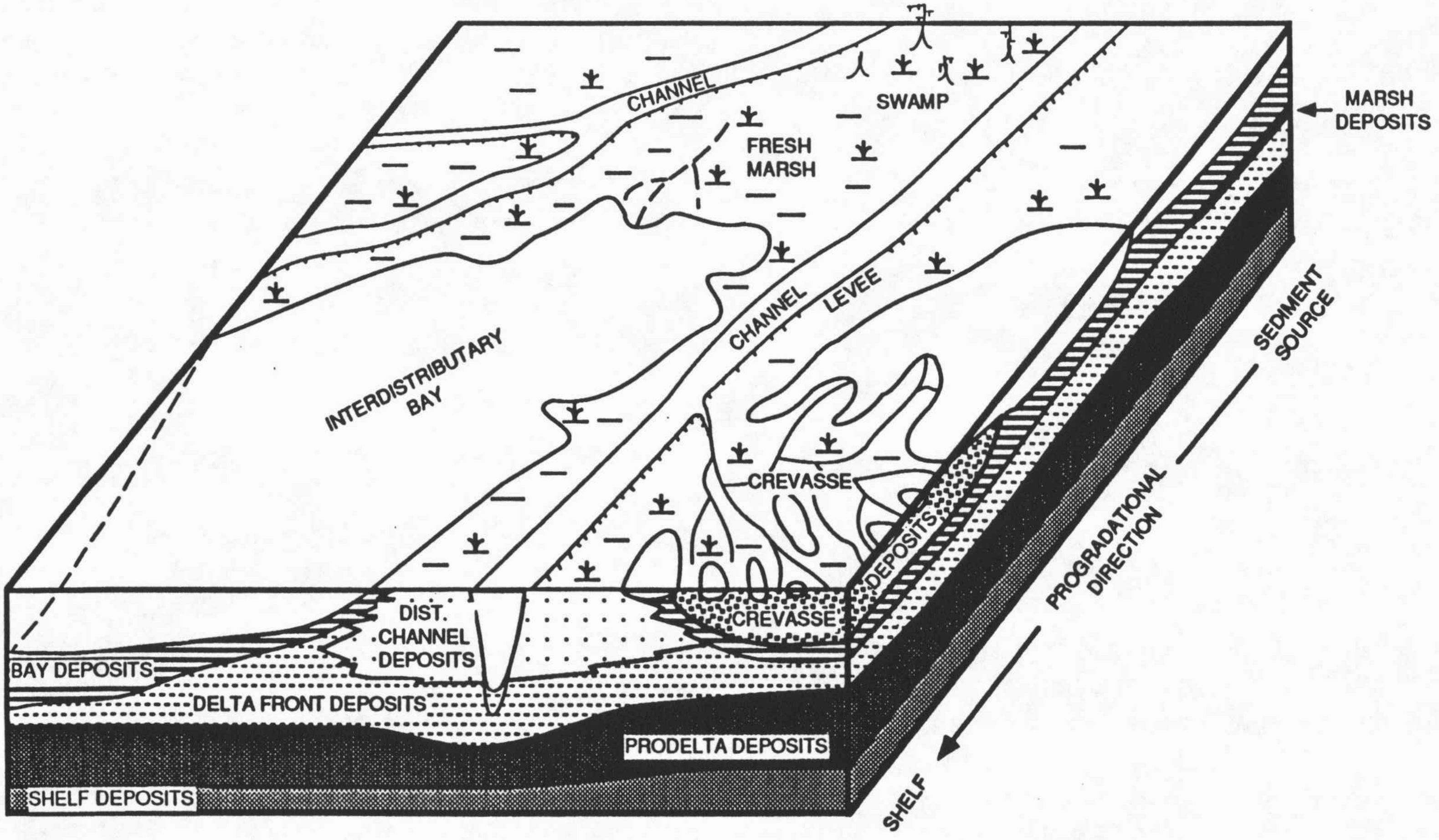
Depositional History and Paleogeography

During the maximum high stand of the Lost Branch transgression, the black muds of the Nuyaka Creek black shale accumulated under anoxic conditions (Heckel, 1991). During the late Lost Branch regression, prograding marine to transitional gray mud shales were deposited above the Nuyaka Creek black shale. This prodeltaic deposit is dominated by clay shales with brachiopods and crinoids followed by clayey silts.

As the sea withdrew from the Cherokee shelf during late Hepler regression, an overall coarsening-upward sequence was formed. This increase in coarser clastic sedimentation and the proximal location to the source of the clastics via distributary channels produced the distal bar and distributary bar facies of the prograding delta complex. Heckel (1991) indicated that sand movement in alluvial channels across southeastern Kansas was responsible for at least some sandstone facies of the Hepler Formation. Coal deposits formed in bay-fill/crevasse-splay facies above sea level on the delta plain.

Figure 18 is a paleogeographic reconstruction of a delta prograding across the shelf area with its associated facies showing both lateral and vertical relationships between the lithofacies.

Figure 18. Paleogeographic reconstruction of a prograding delta and the vertical relationships of Hepler sediments in southeastern Kansas. (Modified from Coleman and Prior, 1982).


CHANNEL
SWAMP
FRESH MARSH
MARSH DEPOSITS
INTERDISTRIBUTARY BAY
CHANNEL
LEVEE
SEDIMENT SOURCE
CREVASSE
DEPOSITS
DIST. CHANNEL DEPOSITS
CREVASSE
BAY DEPOSITS
DELTA FRONT DEPOSITS
PRODELTA DEPOSITS
SHELF DEPOSITS
PROGRADATIONAL DIRECTION
SHELF

DIAGENESIS

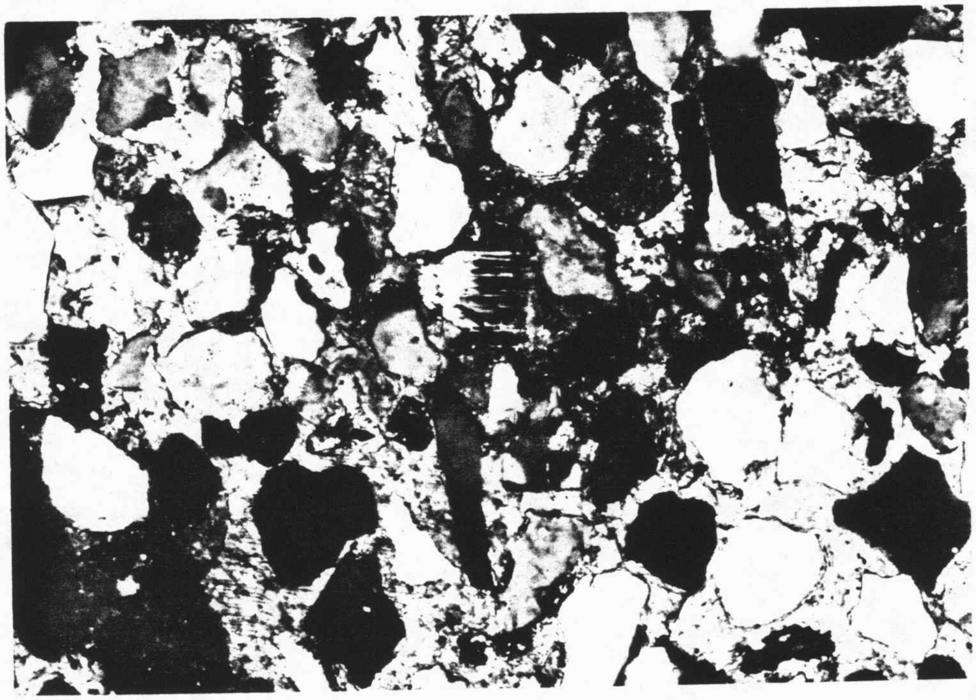
Carbonate Cementation

Based on distribution and microscopic fabrics, two generations of calcite cementation occur within the sediments of the Hepler Formation: 1) an early, localized, poikilitic cement; and 2) an isolated "patchy" euhedral to subhedral pore filling and replacement cement that forms late in the diagenetic history of the formation. These carbonates are the most common intergranular cementing materials and their mobilization and precipitation are dependent on pH, temperature, pressure, and amount of CO_2 in the system (Land, 1984).

Early Carbonate Cement

Early carbonate cementation of Hepler sediments is characterized by a poikilitic texture, large crystals in optical continuity that envelop detrital grains. Nucleation occurred on several "floating" detrital grain types that show little grain to grain contact. Evidence of enveloped grain corrosion by cementing fluids occurs along outer grain margins in the form of etching and small embayments. Cement stratigraphy indicates that calcite precipitation occurred prior to the formation of quartz overgrowths and the significant influence of compactional processes, but post dates feldspar dissolution (Figure 19). Early carbonate precipitation is possibly penecontemporaneous with authigenic quartz precipitation, but occurs under different conditions later in the Hepler's diagenetic

Figure 19. Photograph of early "poikilitic" calcite cement. Note dissolved feldspar (arrow) and lack of grain to grain contacts. Calcite cementation postdates feldspar dissolution due its filling of feldspar mold.Crossed polarizers. Sample EP 0.9.



history. This early stage of carbonate cementation prevented more compaction or further diagenetic modifications from occurring in the observed Hepler interval.

The early calcite cement comprises up to 37 volume percent of the sampled rock. This early form of cementation is localized and occurs in three samples from two surface locations.

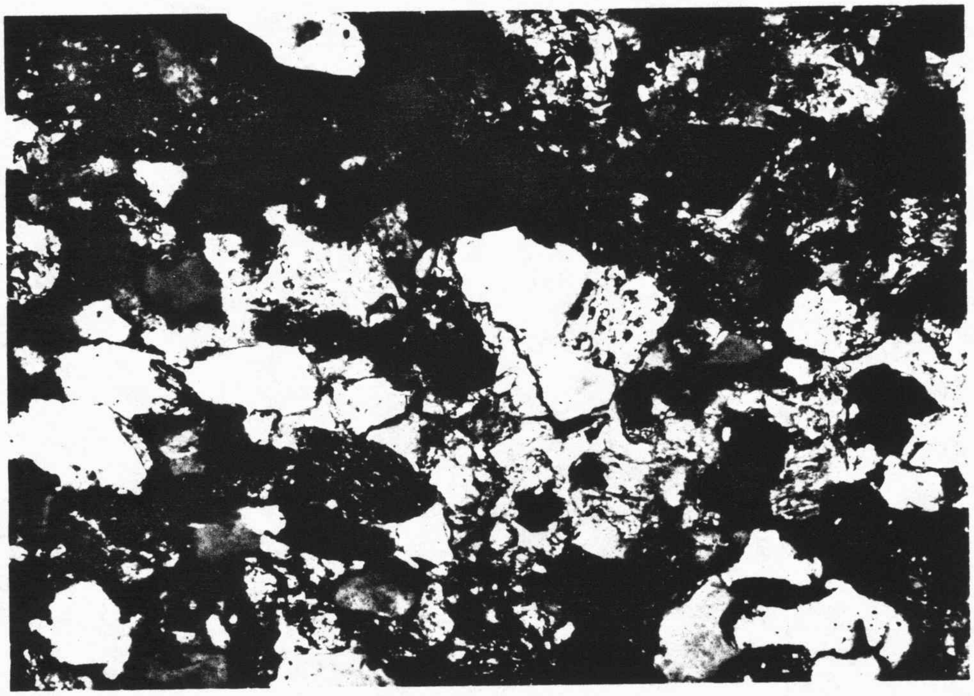
Late Carbonate Cement

Late carbonate cement fabrics include: infills of residual pore space that remained after compaction led to a closer packing arrangement of Hepler sediments and as a replacement of detrital grains. Both fabrics produce an isolated "patchy" texture (Figure 20). Late carbonate cements are observed as partial replacements of detrital quartz grains as indicated by small-scale dissolution features along grain margins and as large-scale embayment infills of framework grains. Cement composition ranges from iron-free calcite to ferroan calcite in Hepler sediments. Late carbonate cements of the Hepler Formation are common in both surface exposures and core samples.

Boles and Franks (1979), suggested that the formation of late diagenetic carbonate cements depends on the availability of Ca^{2+} and $CO_3{}^{2-}$ in interstitial waters. A potential source of Ca^{2+} in the sandstones and siltstones of the Hepler is the release of Ca^{2+} ions during smectite-illite alteration in the clays of adjacent shales similar to the mechanism proposed by Boles and Franks (1979):

$$\text{smectite} + K^{+} = \text{illite} + H_4SiO_4 + \text{cations } (Ca^{2+}, Mg^{2+}, Na^{+}, Fe^{2+}) \qquad (1)$$

Figure 20. Late "patchy" ferroan calcite cement. Note corrosive nature of grain boundaries. Crossed polarizers. Sample SEP 1.9.



This reaction provides a mechanism for both the release of Ca^{2+} and Fe^{2+} ions. A potential mechanism for CO_2 generation in shales is the production of acidic pore waters by decarboxylation of kerogen in organic-rich shales (Curtis, 1983):

$$RCO_2H \text{ (kerogen)} = RH \text{ (kerogen)} + CO_2 \qquad (2)$$

(R = High molecular weight organic substrates)

CO_2 is released from the organic matter and dissociates in the pore waters, forming carbonic acid:

$$CO_2 + H_2O = H^+ + HCO_3^- \qquad \text{(Curtis,1983)} \qquad (3)$$

Given a source of Ca^{2+} ion (equation 1), the dissolved bicarbonate ion could be incorporated into the formation of carbonate cement:

$$Ca^{2+} + HCO_3- = CaCO_3 + H^+ \qquad (4)$$

Blatt et al. (1972), indicated that an increase in pH would increase the abundance of carbonate ions. A pH of 9 or greater is needed to initiate this process. Blatt (1979) argued that with an increase in burial depth, calcite solubility decreases with an increase in temperature (due to the escape of carbon dioxide gas), although solubility increases with lithostatic pressure, the result was a net effect of decreased solubility of calcite with increasing burial depth.

Cement stratigraphy shows calcite replacement of quartz as indicated by the truncation of both syntaxial quartz overgrowths and the detrital grain (Figure 21). Pettijohn et al.(1987), outlined a mechanism that may be responsible for the replacement process (Figure 22). In generally basic (pH >9) ambient waters, a thin film of water undersaturated with respect to silica permits dissolution of quartz. The hydrated silica diffuses into the pore-water. At the same time pore-waters are

Figure 21. Photograph of calcite replacement of quartz. Calcite shown to truncate both the quartz overgrowth and the detrital grain. Crossed polarizers. Sample TR 120' 10".

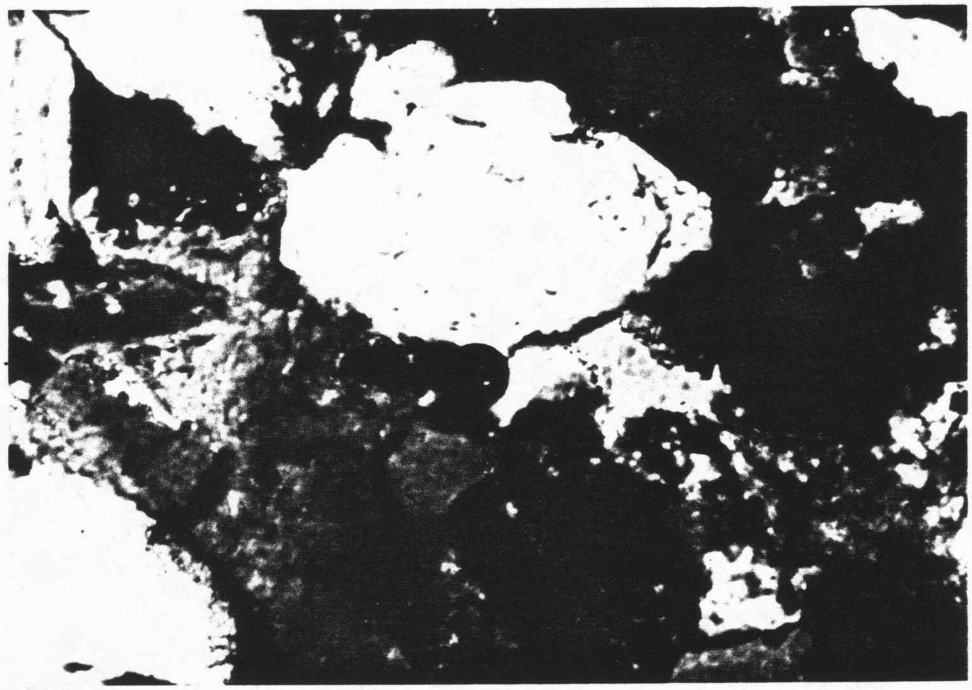
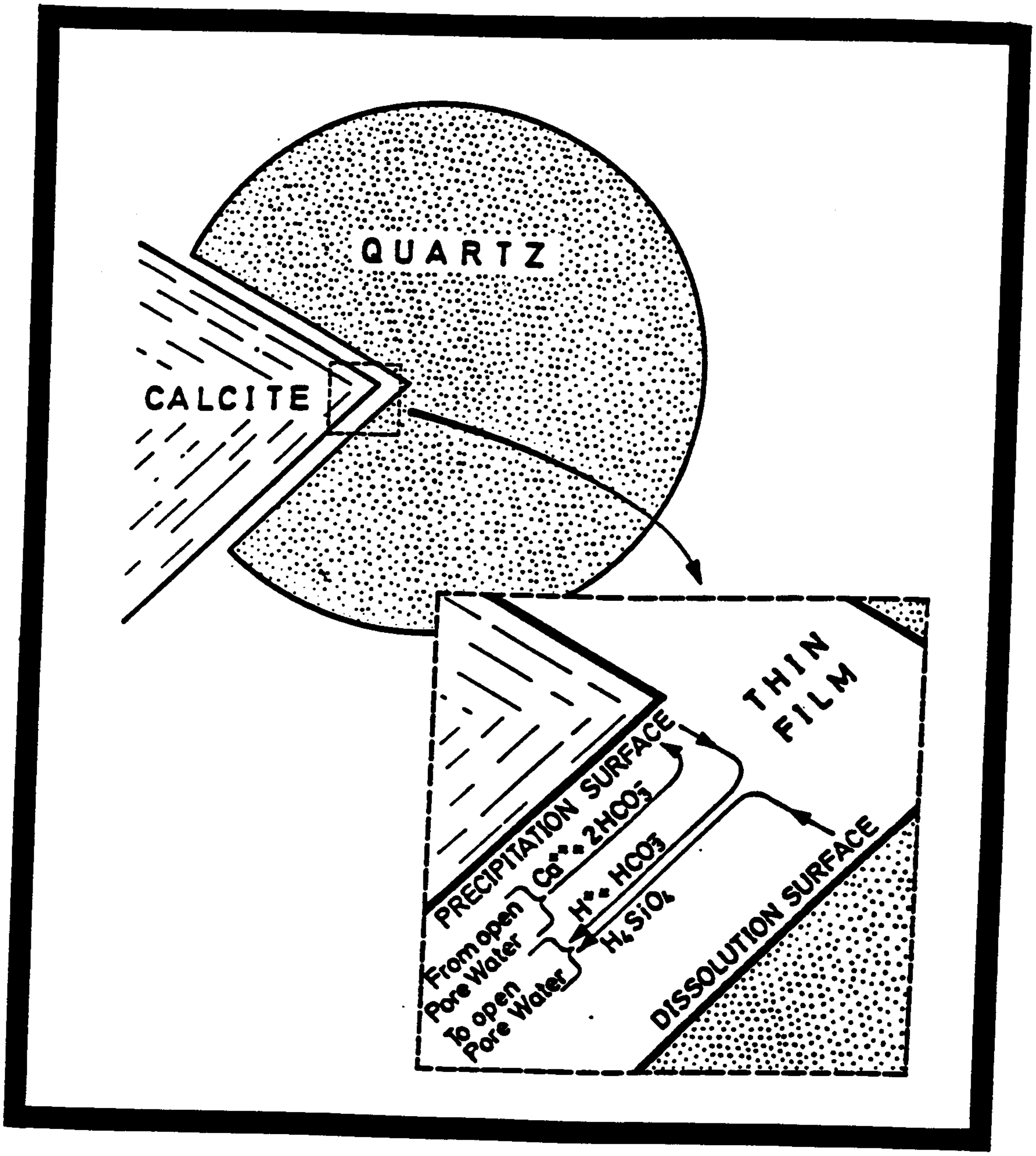


Figure 22. Proposed model for calcite replacement of quartz. See text for discussion of process. (After Pettijohn et al., 1987).


QUARTZ
CALCITE
THIN FILM
PRECIPITATION SURFACE
$Ca^{++} + 2HCO_3^-$
$H^+ + HCO_3^-$
H_4SiO_4
From open Pore Water
To open Pore Water
DISSOLUTION SURFACE

oversaturated with respect to calcite and diffuse into the film between the quartz grain and the encroaching cement. Calcite precipitates at the margins of the calcite crystal and replaces the quartz grain.

Silica Cementation

Silica cementation comprises up to 6.4 percent of the rock volume in Hepler sandstones and siltstones. Authigenic quartz overgrowths formed in the early stages of diagenesis, and they minimized the effects of lithostatic compressional forces on intergrain contacts. Authigenic quartz precipitation requires supersaturation of interstitial pore-waters with respect to silica. Nucleation of overgrowths on detrital grains is indicated by "dust rim" envelopment between the two constituents and these are composed of clays, organic material, or iron oxide. Overgrowths consist of both euhedral and subhedral morphologies and create a reduction of porosity by precipitation into open pore space (Figure 23). The abundance of silica overgrowths decreases with an increase of pore lining and pore filling clay matrix. The clay matrix occludes pore space and insulates the surface of the detrital quartz grains from contact with pore-waters and with the low permeability of the clay matrix reduces the influx of silica-bearing fluids (Smosna, 1988).

Silica solubility is controlled by the following parameters: 1) pH; 2) temperature; 3) pressure; and 4) the presence of other ions in solution (Krauskopf, 1959). Silica solubility is increased with pH values of 9 or above, a rise in temperature, and an increase in lithostatic pressures with burial (Blatt, 1979).

Figure 23. Scanning electron micrograph showing quartz overgrowths invading open pore space causing a reduction in porosity. Sample TR 115'.


VD9
D859521 15 kV x1.50K 20.0μm

Possible sources of silica required for the precipitation of silica cement in Hepler sediments include: 1) pressure solution as a localized source of silica (Sibley and Blatt,1976; Blatt, 1979). Pressure solution mobilizes SiO_2 into pore fluids, which become supersaturated with respect to silica, causing it to precipitate as overgrowths. This process would account for only small amounts of silica mobilization in Hepler sediments because only minimal pressure solution features were observed. 2) The conversion of smectite to illite (equation 1) and the transportation of silica-rich pore-waters from adjacent or interstratified shales into the sandstone and siltstone units (Hayes, 1979). Boles and Franks (1979) suggested that this reaction releases approximately 15 moles of silica for each mole of smectite. Hower and others (1976) proposed the reaction:

$$\text{K-feldspar} + \text{smectite} = \text{illite} + \text{chlorite} + \text{quartz} \qquad (5)$$

which releases 3 moles of silica for each mole of smectite into pore-waters. The problem of fluid transport of silica from shales into adjacent sandstones is the volume of water required to complete the process. Ongoing compaction and diagenesis of shales probably would fail to provide an adequate volume of water (Schwartz and Longstaffe, 1988). Land (1984) proposed a large-scale convection of fluids that cycles connate fluids or meteoric waters through sandstones and shale, within a basin. Descending ground water (Bjørlykke, 1984) or vertically circulating meteoric water (Blatt, 1979) could provide the additional fluids needed to complete the process. 3) The chemical alteration of mineralogically unstable rock constituents such as feldspars and metamorphic rock fragments. Bjørlykke (1984), suggested that for each volume of feldspar altered, a conversion to approximately 60 % kaolinite and 40% quartz is achieved.

Clay Cements and Feldspar Alteration

Kaolinite

Kaolinite is characteristically a well crystallized face to face pseudohexagonal plate (books) pore filling clay (Figure 24). It is the most commonly observed mineral alteration in the sandstones and siltstones of the Hepler. Hurst and Irwin (1982) associated authigenic kaolinite formation with the dissolution of feldspars brought about by the influx of acidic waters produced by the addition of CO_2 released as a result maturation of organic matter in shales (equation 2). Authigenic kaolinite formation in Hepler sediments may be produced by a mechanism similar to the process of feldspar dissolution and precipitation of kaolinite and quartz proposed by Bjørlykke (1984):

$$\underset{\text{(feldspar)}}{2KAlSi_3O_8} + 2H_2CO_3 + 9H_2O = \underset{\text{(kaolinite)}}{Al_2Si_2O_5(OH)_4} + \underset{\text{(quartz)}}{4H_4SiO_4} + 2HCO_3^- + 2K^+ \quad (6)$$

The feldspar dissolution reaction will produce 60% kaolinite and 40% quartz, which as discussed before may aid in the formation of quartz overgrowths. For the above reaction to occur, released potassium must be removed so that pore-water composition remains in the stability field of kaolinite (Bjørlykke, 1984). Potassium removal may be accomplished by equation 1 showing the conversion of smectite to illite.

Chlorite

Authigenic chlorite formation in Hepler sediments is observed as individual pseudohexagonal plates that have a face-to-edge orientation forming a two-dimensional cardhouse arrangement (Figure 25). Chlorite clays in the Hepler are observed as pore lining cements. The formation of chlorite requires an interstitial water supply rich in Si, Fe, and Mg ions. A potential source for the

Figure 24. Scanning electron micrograph showing kaolinite "books" lining pore space. Sample PuC 2.1.

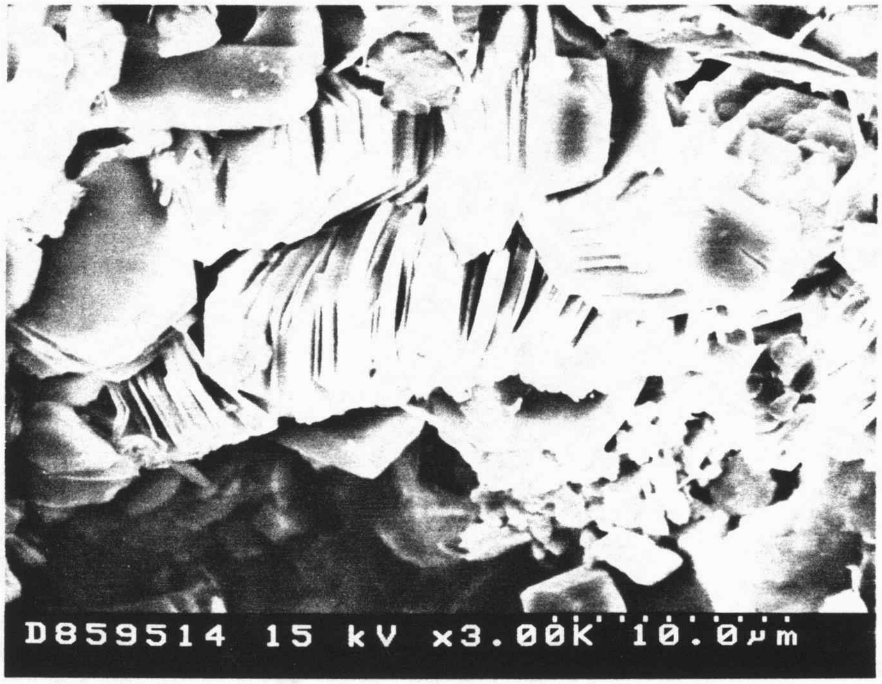
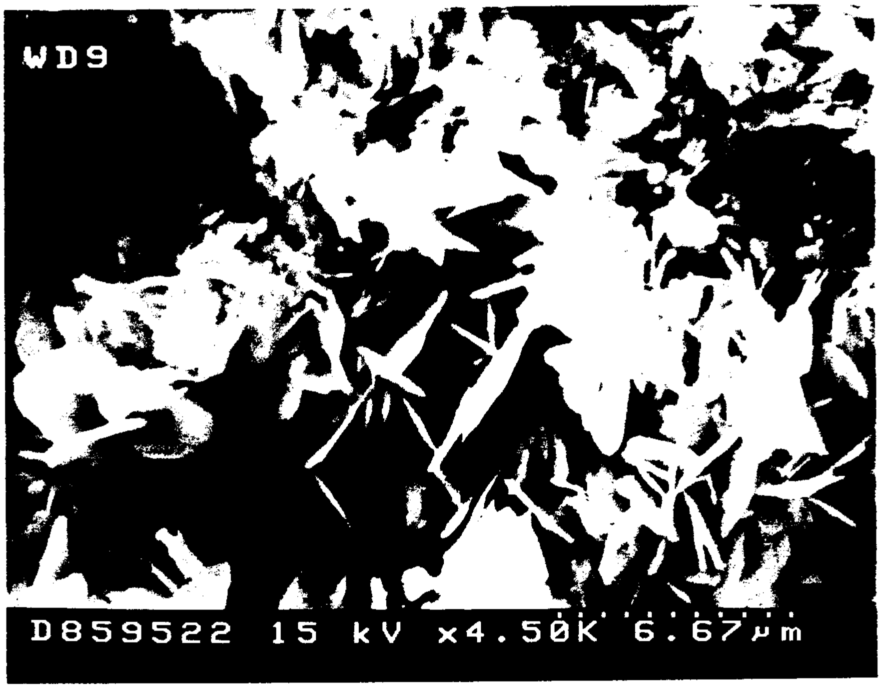

D859514 15 kV x3.00K 10.0μm

Figure 25. Scanning electron micrograph of face-to-edge "cardhouse" pore lining chlorite clay. Sample EM 164'3".


WD9
D859522 15 kV x4.50K 6.67μm

mobilization of these ions is the previously discussed Boles and Franks (1979) proposed conversion of smectite to illite (equation 1) in adjacent shale units. With the availability of biotite in Hepler sediments and the observed dissolution features of feldspar, Fe and Mg could be released from the alteration of biotite and Si could be released from the dissolution of feldspars. Another possible explanation for the formation of chlorite is the reaction proposed by Boles and Franks (1979) signifying a conversion of kaolinite to chlorite:

$$3.5Fe^{2+} + 3.5\ Mg^{2+} + 6H_20 + \underset{\text{kaolinite}}{Al_2Si_2O_5(OH)_4} = \underset{\text{chlorite}}{Fe_{3.5}Mg_{3.5}Al_6Si_6O_{20}(OH)_{16}} + 14H^+ \qquad (7)$$

The above reaction provides a framework for the timing of authigenic chlorite formation. According to the above reaction chlorite formation must post date kaolinite formation in the diagenetic sequence.

Pyrite

Authigenic pyrite is observed in trace amounts as a replacement of organic material in Hepler sediments. Fairbridge (1983) suggested that the activity of sulfate-reducing bacteria produces H_2S, which in the presence of dissolved iron or Fe-hydroxide is transformed into hydrotroilite ($FeS{\cdot}nH_2O$). After a period of time the stable iron sulfide pyrite FeS_2 is formed. With the importance of bacterial activity in the process, pyrite had to form early in the diagenetic history of the sediment when bacteria were still active and the nutrient supply was abundant (Berner, 1980). Pyrite is most common in the Marsh/Swamp lithofacies of the Hepler where reducing conditions, low pH, abundant organic carbon sources and high dissolved-sulfur concentrations were present, conditions similar to those commonly found in present day marsh environments (Coleman and Prior, 1982).

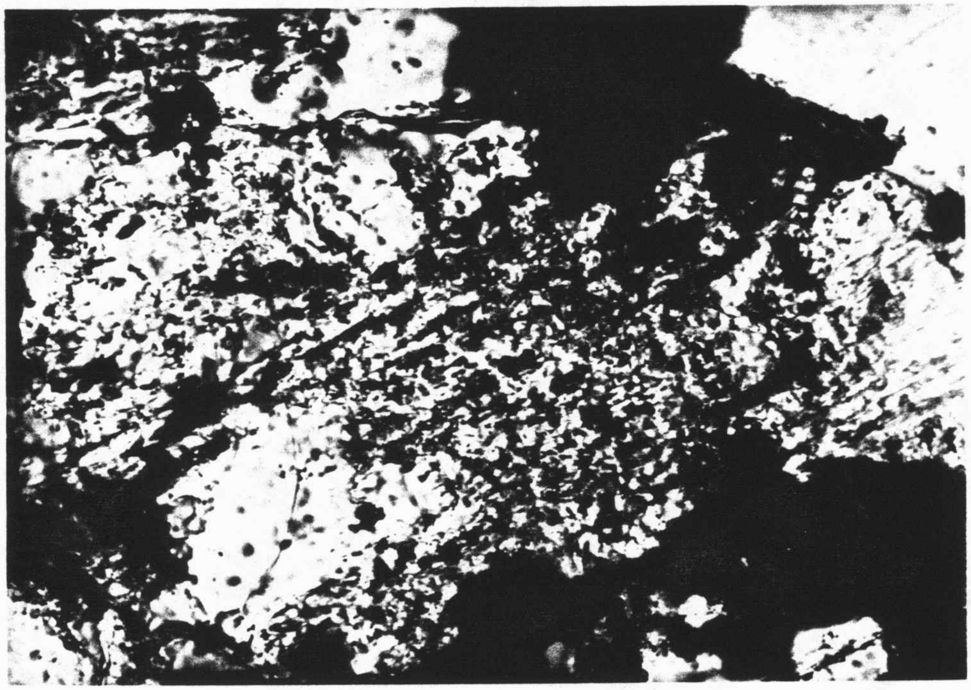
Fe-0xide Cement

Fe-oxide cement is found most commonly in surface exposures and compose on the average approximately 7 percent volume of the analyzed rock samples. Fe-oxide cement in the Hepler is observed as a reddish-brown coating on grains and as a pore-lining cement. SEM analysis indicates Fe-oxide cement composition to be goethite. Cement formation occurs under oxidizing conditions as a weathering product of iron-bearing minerals. Possible sources of iron in the Hepler include: biotite, chlorite, certain clays and dissolution of ferroan calcite cement. The circulation of meteoric water is necessary to maintain oxidizing conditions within the permeable strata to allow "limonite" staining of the underlying sediments. The occurrence of goethite is limited to modern sediments and highly weathered outcrops (Fisher, 1963). Therefore, the formation of Fe-oxide cements occured late in diagenetic history of the Hepler when sediments were exposed to the meteoric regime and weathering processes.

Secondary Porosity

Recognition of secondary porosity in the sediments of the Hepler Formation is based on the observation of oversized pores and the presence of "honeycombed" grains, which are in agreement with diagnostic criteria established by Schmit and McDonald (1979). Feldspar dissolution in both outcrop and subsurface samples is the primary mechanism for the creation of secondary porosity (Figure 26). Secondary porosity is enhanced in surface

Figure 26. Photograph of feldspar grain undergoing dissolution and creation of secondary porosity. Dark areas are Fe-oxide cement Plane light. Sample TP 7.0.



samples by the dissolution and leaching of the late stage carbonate cement. Average secondary porosity observed in outcrop is 6.2 percent compared to 5.6 percent in core samples.The above mentioned criteria for secondary porosity accounts for up to 16% of open pore space observed in Hepler sediments.

For feldspar alteration (Figure 27) and dissolution to occur, a source for the creation of acidic pore waters must be present (Tillman and Almon, 1979). Generation of acidic pore waters can be accomplished with the thermal maturation of organic matter as previously outlined in equations 2, 3 and 4 (Curtis, 1983). The CO_2 produced from the above reaction and the oxidation of plant material abundant in the Hepler are probably the source of acid.

The increase in secondary porosity of outcrop samples is the result of late-stage carbonate cement dissolution. This is initiated by an influx of meteoric water at near surface pressure and temperatures (Pettijohn *et. al.*, 1972).

Paragenesis

Based on petrographic examination of grain alteration, cement stratigraphy and geochemical considerations, a paragenetic sequence for the sediments of the Hepler Formation in southeastern Kansas can be constructed (Figure 28): 1)feldspar dissolution; 2) early calcite cementation; 3) compaction; 4) feldspar alteration; 5) kaolinite formation; 6) silica cementation; 7) chlorite formation; 8) late replacement calcite cement; 9) iron oxide cement. The sequence was delineated by noting the relative positions of the various diagenetic products to each other even though all features do not occur in all samples.

Figure 27. Feldspar grain altered to kaolinite (arrows) and framework grain (F) dissolution forming secondary porosity.Dark areas are late forming Fe-oxide cement Plane light. Sample TP 7.0.

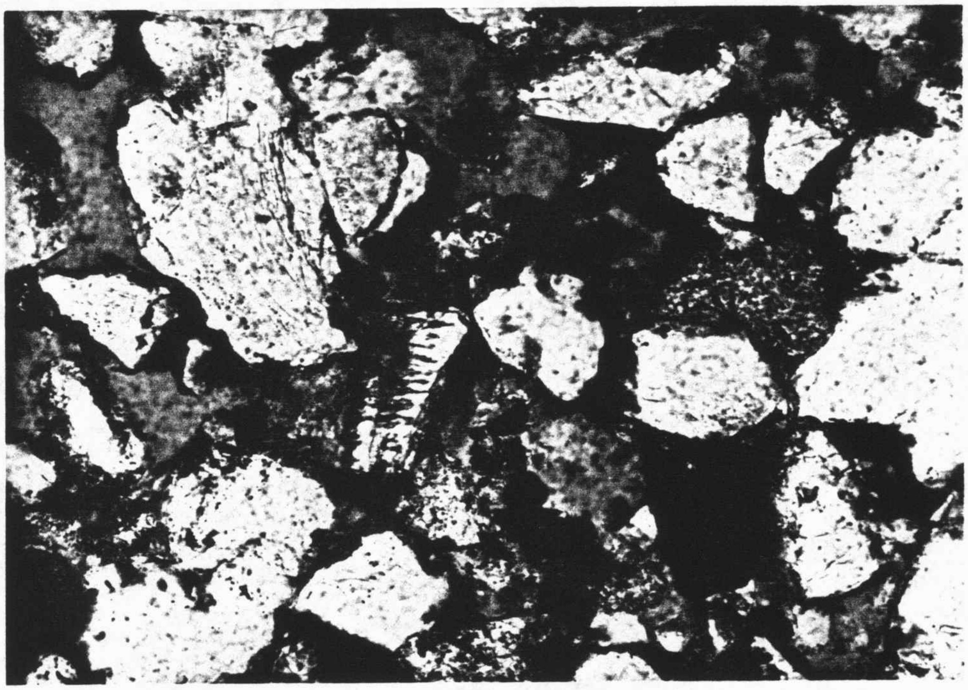
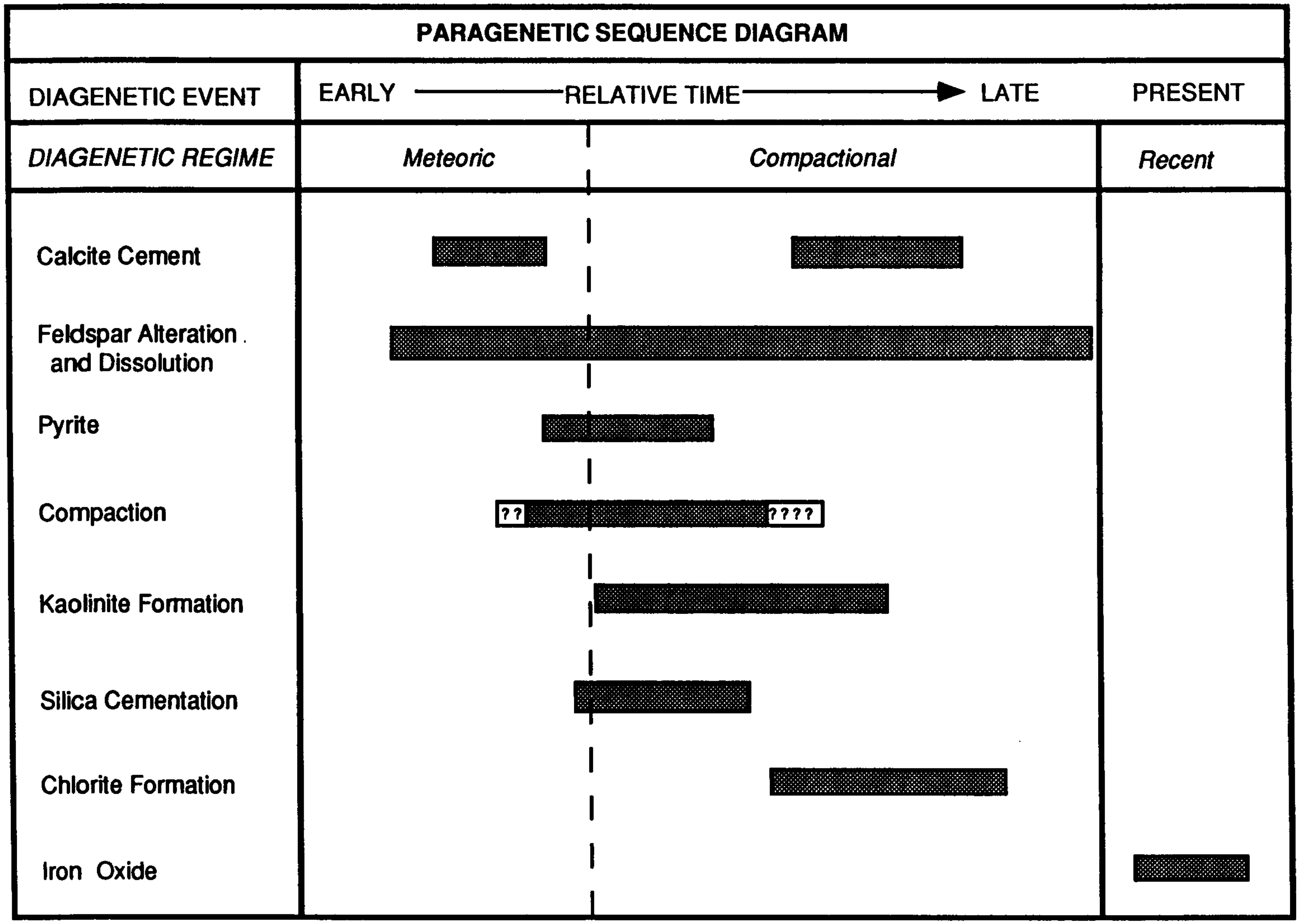


Figure 28. Proposed paragenetic sequence for the Hepler Formation in southeastern Kansas.

[redacted]


PARAGENETIC SEQUENCE DIAGRAM
DIAGENETIC EVENT
EARLY
RELATIVE TIME
LATE
PRESENT
DIAGENETIC REGIME
Meteoric
Compactional
Recent
Calcite Cement
Feldspar Alteration and Dissolution
Pyrite
Compaction
??
????
Kaolinite Formation
Silica Cementation
Chlorite Formation
Iron Oxide

Galloway (1984) subdivided the subsurface hydrologic system of an actively filling basin into the meteoric regime, compactional regime, and thermobaric regime. The sediments of the Hepler Formation have undergone diagenetic changes associated with both the meteoric regime and compactional regime

The meteoric regime encompasses shallow portions of the basin fill where sediments of the Hepler were exposed to meteoric-vadose and meteoric-phreatic waters. The compactional regime is characterized by upward and outward expulsion of pore waters trapped within the compacting sediment pile. The thermobaric regime lies in the deepest portion of the basin where dehydration reactions of clay minerals can release volumes of water into the system driven by high temperature and pressure derived from lithostatic loading and crustal heat flow. Thermobaric regime conditions were probably not experienced in the shallow portions of the tectonically stable midcontinent and therefore did not directly effect sediments of the Hepler Formation.

Poikilitic calcite cementation occured early in the diagenetic history of the Hepler Formation as evidenced by the poikilitic texture and scattered fossil fragments. Formation of this early calcite cement probably occured early as slightly oversaturated meteoric waters perhaps from dissolution of shell material slow development of large crystals around remaining skeletal nucleation sites. Lack of deformation of ductile grains, lack of quartz overgrowths and altered feldspars show little evidence of exposure to compactional forces, indicating that compaction postdated this calcite formation. Early pyrite formation occurred in anoxic parts of the meteoric regime where conditions were favorable for bacterial processes to replace organic material. Unstable mineral components such as feldspars were altered in the meteoric regime by the influx of acidic meteoric pore waters brought on with the lowering of pH due to the decay of organic matter. This could initiate the early formation of kaolinite depending upon Si and Al ions availability. Feldspar degradation continued throughout the diagenetic history of the Hepler. Leached and skeletal feldspar grains show no sign of compactional effects, therefore, compaction occurred before considerable dissolution of feldspars.

Compaction of Hepler sediments began after the deposition of transgressive Exline Limestone and South Mound Shale units. With little suturing and only scattered concavo-convex grain to grain contacts, sediments of the Hepler Formation were not exposed to great lithostatic pressures. Compaction of Hepler and underlying sediments did provide a mechanism for the mobilization of ions released from diagenetic reactions in the underlying shale units. Movement of the released ions was accomplished with the flush of phreatic compactional waters from underlying units into the overlying Hepler sediments. Feldspar alteration occured before the formation of kaolinite. This is evidenced by the alteration of feldspar grains to kaolinite and the presence of clay rims around detrital grains. Kaolinite formation is dependent upon the mobilization of Al and Si ions released from the alteration of feldspars. Formation of quartz overgrowths resulted from the oversaturation of compactional waters with Si ions due to the alteration of feldspars and the probable conversion of smectite to illite in adjacent shales. The formation of chlorite in the compactional regime requires the availability of both Fe and Mg ions. Fe and Mg ion mobilization could be accomplished through the alteration of biotite and the previously mentioned conversion of smectite to illite (equation 1) in adjacent shale units. Boles and

Franks (1979) proposed a conversion of kaolinite to chlorite (equation 7) that would establish chlorite formation subsequent to kaolinite. The final diagenetic event in the compactional regime is the precipitation of a "patchy" replacement carbonate cement. This phase of carbonate cement precipitation was probably initiated by Ca^{2+} mobilization through clay reactions (Boles and Franks, 1979) and CO_2 generation produced by organic maturation (Curtis, 1983) in adjacent shale units. Carbonate cement precipitation ended when compactional water migration subsided late in the diagenetic histiory of the Hepler.

Recent exposure to modern meteoric waters flushed Hepler sediments during surface weathering processes and enhanced secondary porosity and Fe-Oxide formation in outcrop samples.

CONCLUSIONS

The Upper Pennsylvanian (Missourian) Hepler Formation in southeastern Kansas is a low-stand regressive deposit dominated by siliciclastic sediments. Based upon outcrop sections, cores and geophysical well log analysis, the depositional setting of Hepler sediments is interpreted as a prograding lobate, fluvial-dominated deltaic/alluvial complex that formed as the Midcontinent Sea withdrew from the shelf area in southeastern Kansas during the Late Pennsylvanian.

Four lithofacies are recognized in the Hepler Formation: 1) very fine-to-medium grained, calcite-cemented quartz sandstone; 2) interstratified, bioturbated, carbonaceous siltstone and shale; 3) interstratified convoluted sandstone, siltstone, and shale; and 4) carbonaceous blocky mudstone/coal. These lithofacies have been interpreted as representing distributary mouth bar and possibly later fluvial deposits, distal bar deposits, interdistributary bay/ crevasse splay deposits, and marsh/ swamp deposits, respectively. A fifth clay shale lithofacies representing earlier prodelta deposits belongs to the underlying Lost Branch Formation.

The isopach maps of the Hepler and the interval between the Nuyaka Creek black shale and the Mound City black shale indicate a thinning of sediments from east to west across the map area. Paleosource directions for the siliciclastic sediments of the Hepler is out of the northeast and southeast. Sandstone isolith map and cross-section construction shows that the thickest sands were deposited in elongate bodies oriented from east to west and thin towards the west. Petrographic analysis of core and outcrop samples show that the sandstones of the Hepler Formation are fine-grained to medium-grained quartz arenites, sublitharenites, and litharenites. Lithic fragments consists of primarily mica schist. Muscovite is the dominate mica observed in the schist fragments. Hepler sediments contain significant amounts of both muscovite and biotite grains and lack preserved feldspars. The high percentages of both muscovite schist fragments as well as mica grains suggests a probable metamorphic dominated source area.

After deposition, diagenetic processes in the meteoric and compactional regimes of the subsurface substantially altered Hepler sediments. Early in the diagenetic history, before much compaction took place poikilotopic calcite cement was precipitated from interstitial waters that were oversaturated with respect to $CaCO_3$. Feldspar grain alteration to kaolinite occurred in the meteoric regime with decaying organic matter lowering the pH of the waters. Subsequent compaction provided a flush of compactional waters, due to lithostatic pressures initiated by further deposition of overlying sediments and deeper burial of Hepler sediments. The compactional waters provided a medium for ion transport from clay diagenesis reactions in adjacent shales through the permeable siltstones and sandstones of the Hepler. Silica overgrowths, chlorite formation, and the later precipitation of a patchy pore-filling calcite cement occurred under compactional regime conditions. Later exposure to surface weathering processes further enhanced secondary porosity and precipitated Fe-oxide cement from dissolution of iron-rich calcite and the weathering of iron-bearing detrital components.

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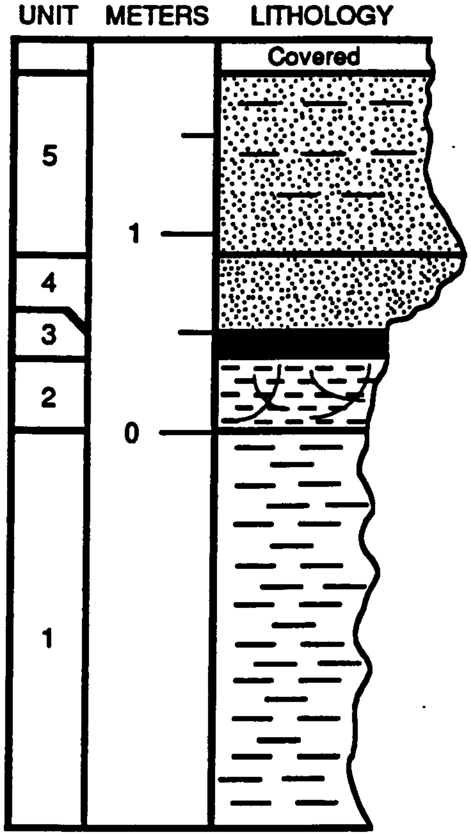
APPENDIX A:

OUTCROP AND CORE DESCRIPTIONS

SECTION: UNIONTOWN SOUTH (US)
IN RAVINE ~ 400 W OF ROAD CUT ON K-3
LOCATION: SW/NE/NW SEC.34, T25S,R22E.

STATE: KANSAS

COUNTY: BOURBON



Unit 5: (0.8-1.7 M) Interbedded fine-grained sandstone and shale; micaceous; calcite-cemented; carbonaceous; Gradational basal contact.

Unit 4: (0.5- 0.8 M) Sandstone; fine-grained; micaceous; calcite-cemented; sharp basal contact.

Unit 3: (0.3-0.5 M) Coal; plant debris; gradational basal contact.

Unit 2: (0.0-0.3 M) Underclay; mudstone;blocky; plant debris; Forms base of Hepler Formation; gradational basal contact.

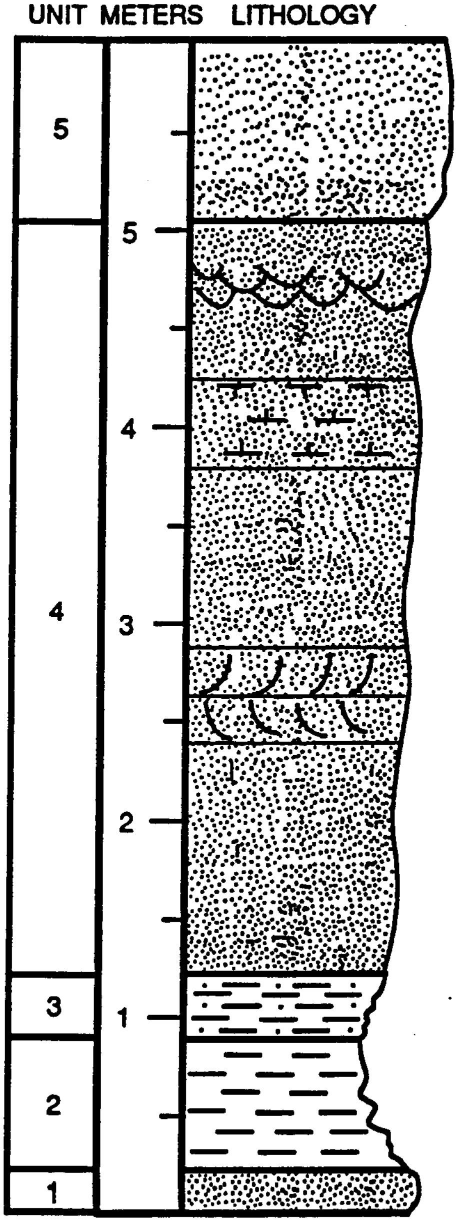
Unit 1: Gray Shale; undetermined thickness; Top of Lost Branch Formation.

SECTION: EAST PLEASANTON (EP)

STATE: KANSAS

LOCATION: NE/SE/NE SEC.9, T22S, R25E

COUNTY: LINN



Unit 5 ; (5.1-5.8 M) Sandstone; fine-grained at base grading into medium-grained; calcareous; blocky; homogeneous; gradational basal contact.

Unit 4 : (1.2-5.1 M) Sandstone; fine-grained; wavy stratification near base, grading into planar cross-bedding; Fe-stained calcareous throughout; tightly cemented around 4 meter mark (thickness ranges from 0.4 to 0.0 M); micaceous; shale parting throughtout; trough cross-bedding towards top of unit (channel ?); gradational basal contact.

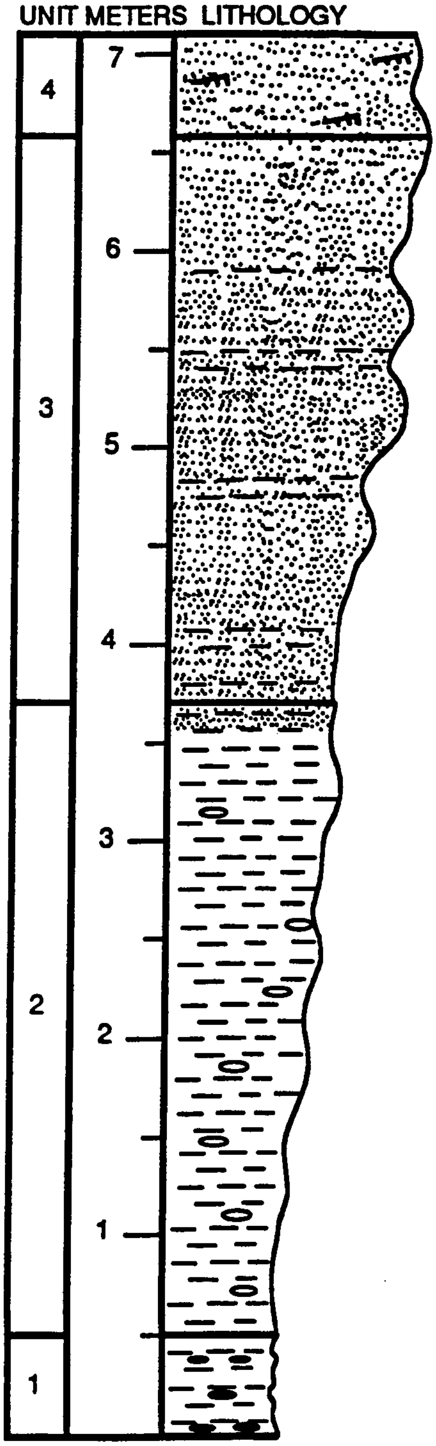
Unit 3 : (0.8-1.2 M) Interstratified fine-grained Sandstone and Shale; Fe-stained; wavy beds. gradational basal contact.

Unit 2 : (0.2-0.8 M) Shale; poorly exposed; Silty towards top.; gradational basal contact.

Unit 1: (0-0.2 M) Sandstone; fine-grained; thinly bedded; poorly exposed; micaceous.

SECTION: TRADING POST ; Marais des Cygnes River (TP) STATE: KANSAS

LOCATION: NW/NW/SW SEC.5, T21S, R25E COUNTY: LINN



Unit 4 : (6.6-7.2 M) Sandstone; fine-grained; Fe-oxide on weathered surfaces; thinly bedded; small scale ripple-laminated; slabby; units 3 and 4 comprise Hepler "C" Formation gradational basal contact.

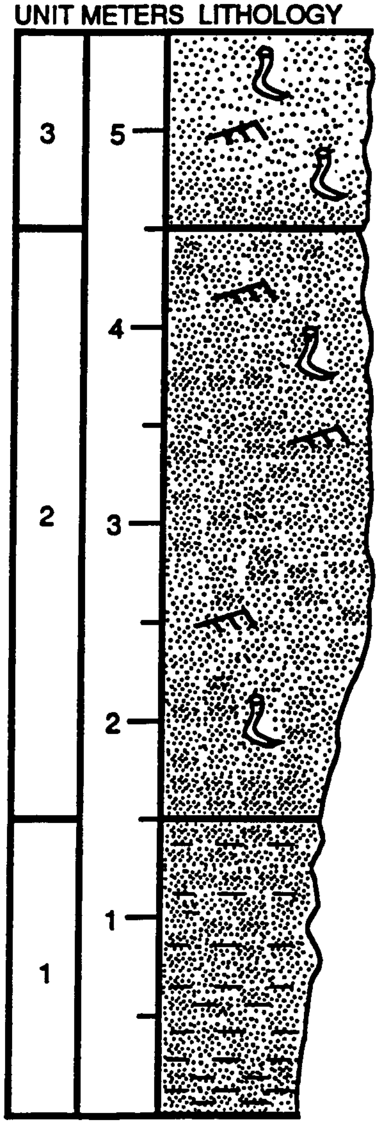
Unit 3 : (3.7-6.6 M) Sandstone; very fine-grained interbedded with shale; shale-sandstone layers vary in thickness 2-10 cm,; grad. basal contact.

Unit 2 : (0.5-3.7 M) Clay shale; medium gray; very fine-grained sandstone towards top; ironstone concretions throughout; Units 1 and 2 comprise the Lost Branch Formation; gradational basal contact.

Unit 1: (0-0.5 M) Clay shale; NuyakaCreek bed;black with phosphate nodules, thinly bedded; base not exposed.

SECTION: SOUTHEAST PLEASANTON (SEP) STATE: KANSAS

LOCATION: NE/SE/NE SEC.9, T22S, R25E COUNTY: LINN



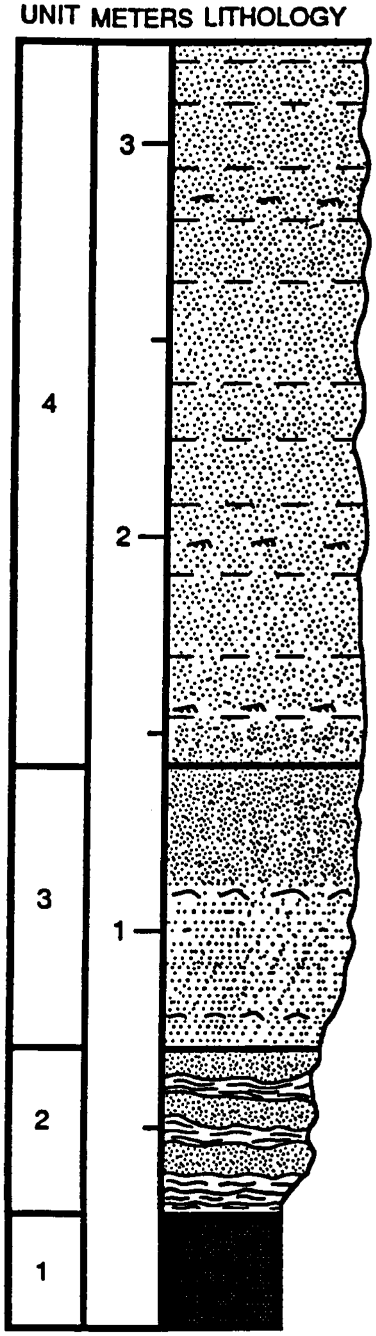
Unit 3: (4.5-5.5 M) Sandstone; fine-to-medium grained; wavy stratification; ripple marks; burrowed; tight calcite-cementation; Fe-oxide cement; gradational basal contact.

Unit 2: (1.5- 4.5 M) Sandstone; fine-grained; Fe-stained; thinly bedded; trace fossils on bedding planes; evidence of burrowing; small scale ripples; gradational basal contact.

Unit 1: (0-1.5 M) Sandstone; very fine-grained; slabby; interbedded with clay shale.

SECTION: PUMPKIN CREEK (PC) STATE: KANSAS

LOCATION: SW/SW SEC.20, T33S, R18W COUNTY: LABETTE



Unit 4: (1.4-3.4 M) Sandstone; very fine to fine-grained; brown fresh surface; intrstrat. micaceous shale partings; small scale ripple-lam. (0.5 to 1.5 cm); shale content increases towards top of section; plant fragments; gradational basal contact.

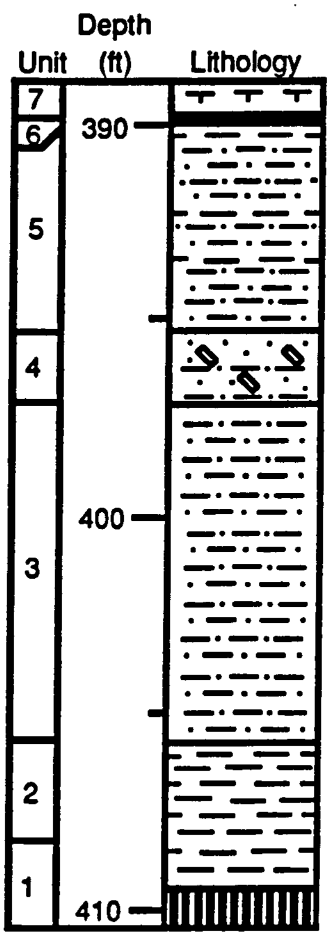
Unit 3: (0.7-1.4 M) Sandstone; fine-grained; ripple laminations; small-scale crossbeds; flaser bedding; massive towards top; micaceous shale partings; carbonaceous; gradational basal contact.

Unit 2: (0.3-0.7 M) Sandstone; very-fine grained; interbedded with med. gray shale; wavy to lenticular bedding; shale is thinly laminated; sharp basal contact.

Unit 1 (0-0.3 M) Coal; black; base is covered.

CORE: GADDY#1 STATE: KANSAS

LOCATION: SE/NE/SE SEC.24, T31S, R16E COUNTY: MONTGOMERY



Core Description

Unit 7 (389'9" to 387"3"): Calcareous Shale, dk. gry., crinoids, brachs. Abrupt lower contact.

Unit 6 (390' to 389'9"): Coal, shaly, fissile, plant frags. Abrupt lower contact.

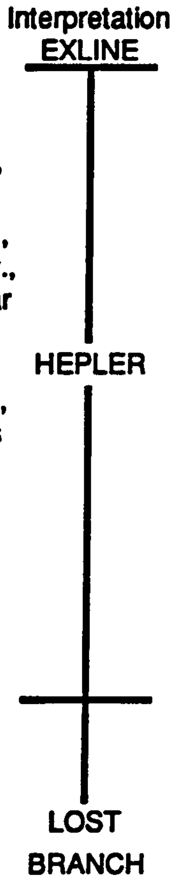
Unit 5 (395'3" to 390"): Shale and intrlam., Siltstone, dk. gry. shale, med. gry., siltstone, calcareous, mottled near base. Grad. lower contact.

Unit 4 (396'5" to 396'5"): Siltstone, med. gry., very fine gr. sandstone beds, calcareous, clasts, mottled, clasts increase towards top of the unit. Grad. lower contact.

Unit 3 (406" to 396'5"): Siltstone, med. gry., mottled, calcareous. Grad. lower contact.

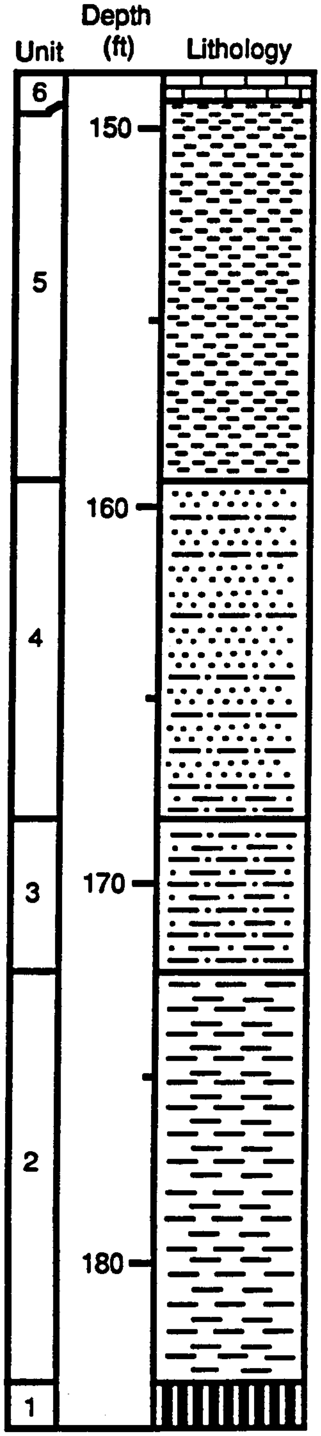
Unit 2 (409'6" to 406'): Clay Shale, gry., fissile, micaceous, phosphate nodules. Abrupt lower contact.

Unit 1 (410'3" to 409'6"): Shale, black. plant frags., phosphate nodules.



CORE: EMERSON #1 **STATE: KANSAS**

LOCATION: SW/NE/NE SEC.14, T24S, R24E **COUNTY: BOURBON**



Core Description

Unit 6 (148'2" to 149'): Limestone, dk. gry., argillaceous, brachs, crinoids Grad. lower contact.

Unit 5 (149' to 159'): Mudstone, med. gry., blocky, caliche deposit (paleosol ?) near upper contact, micaceous, plant frags., burrows, Fe-stains, lam. at base. Grad. lower contact.

Unit 4 (159' to 168'3"): Thin intbd. Siltstone (med. gry.) and fine grained Sandstone (ly. gry.), sandstone dominates the part of the section, burrows, micaceous plant frags., wavy and rippled bedding, mottled near base, Fe concentrated near base. Silt to sand ratio apprx. 50% to 50%. Grad. lower contact.

Unit 3 (168'3" to 173'2"): Siltstone, med. gry., apprx. 80% silt to 20% sand, sandstone lam. throughout but concentration occur near upper contact, below 170'7" lam. are irregular, micaceous, plant frags., burrows, Fe concentrations. Grad.lower contact.

Unit 2 (173'2" to 183'): Clay Shale, dk.gry. to med. gry.in upper part of unit, lam., fossiliferous near base, burrowed, micaceous, plant frags., pyrite at base, abrupt lower contact.

Unit 1 (183' to 185'): Shale, black, fissile, thn. laminated, discordant fracture filled with med. gry. shale and calcite. phosphate nodules.

Interpretation

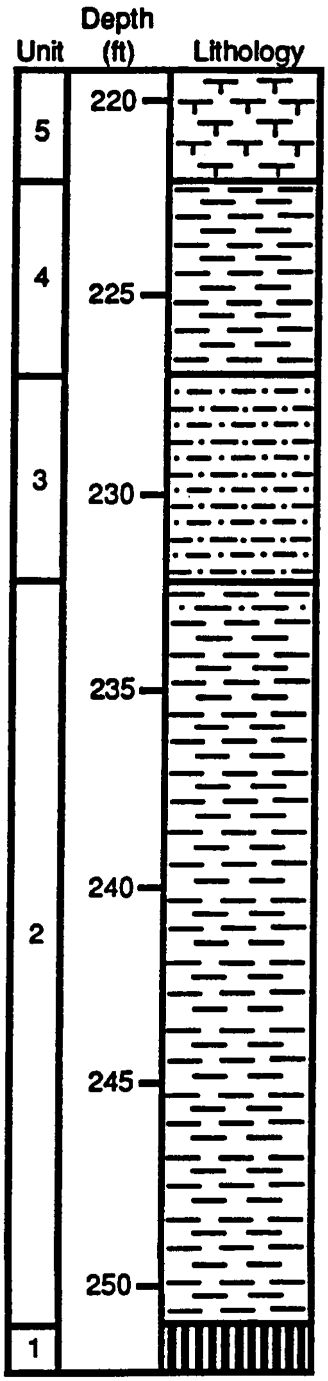
EXLINE

HEPLER

LOST BRANCH

CORE: WOMELSDORF #1 STATE: KANSAS

LOCATION: SW/SE SEC.17, T24S, R23E COUNTY: BOURBON



Core Description

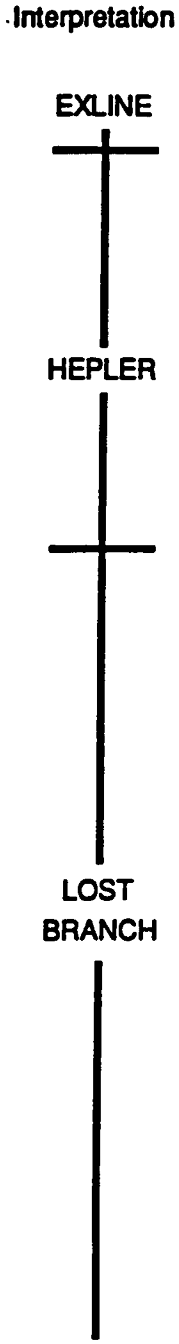
Unit 5 (222'2" T0 218'9"): CalcareousShale, dk. gry., brachs, crinoids, plant frags., micaceous. Abrupt lower contact.

Unit 4 (227' to 222'2"): Shale, med. gry., thin lam., pyrite, micaceous, calcareous near upper contact, bioturbated, silt lenses near base, slickensides. Abrupt lower contact.

Unit 3 (232'1" to 227"): Siltstone, lt. gry., bioturbated, micaceous, plant frags, Fe stains, slickensides, limestone clasts. Grad. lower contact.

Unit 2 (250'9" to 232'1"): Shale, dk. gry. to med. gry., thin and irregular lam., bioturbated, plant frags, micaceous, fissile, brachs, pyrite concentration near base, Fe stains, localized mottling. Abrupt lower contact.

Unit 1 (252'2" to 250"9"): Shale, black, thin lam., fissile, plant frags, micaceous small pyrite fracture fills near base.

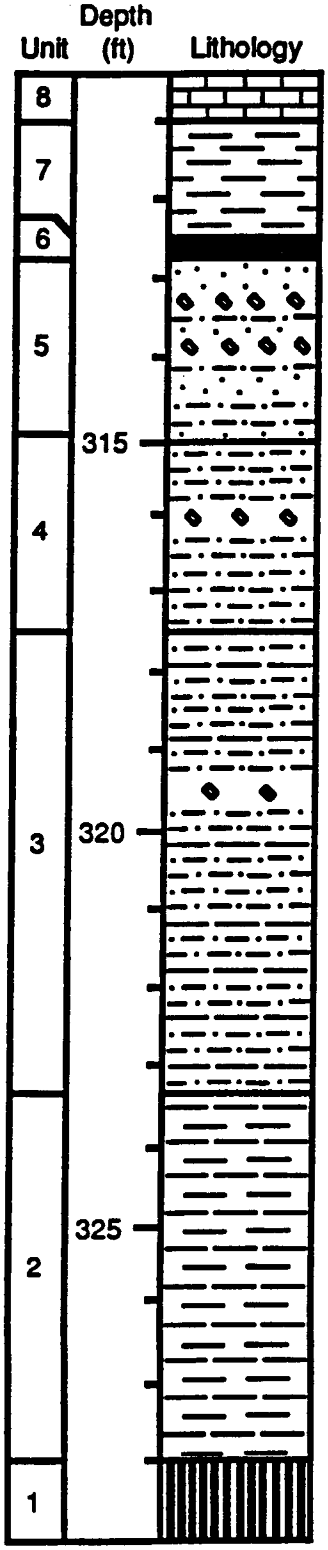


CORE: NEWLAND #1

LOCATION: SE/NE/ NW SEC.6, T30S, R17E

STATE: KANSAS

COUNTY: WILSON



Core Description

Unit 8 (311' to 310'7"): Limestone, med. gry., crinoids, brachs. Abrupt lower contact.

Unit 7 (312'5" to 311"): Shale, dk. gry., Ls. clasts, calcareous, wavy lam. Abrupt lower contact.

Unit 6 (312'11" to 312'5"): Coal, fissile, plant frags., 1" underclay. Abrupt lower contact.

Unit 5 (315' to 312'11"): Very fine gr. Sandstone and intbd. Siltstone, lt. gry. sands to med. gry. silts, Ls. clasts, mottled and contorted bedding, calcareous, unit coarsens towards top. Abrupt lower contact.

Unit 4 (317' 3" to 315"): Gr-gry. Siltstone, Ls. clasts, calcareous. Grad. lower contact.

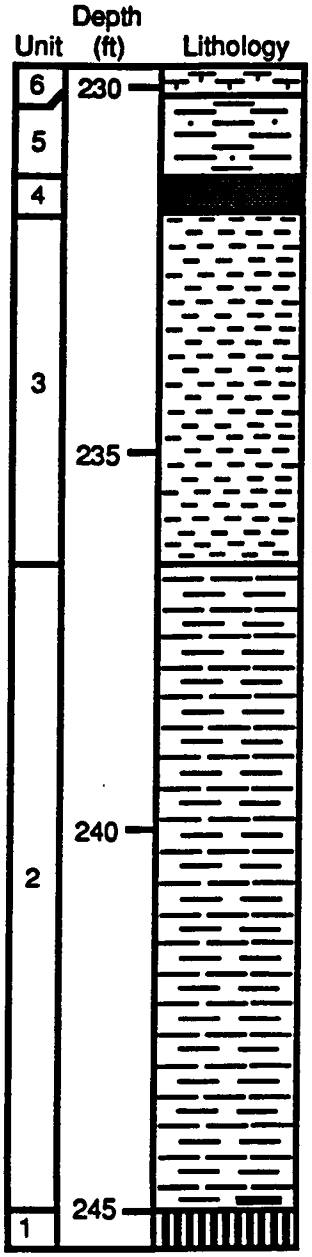
Unit 3 (323'5" to 317'3"): Intbd. lt. gry. Siltstone and dk. gry. Shale, unit coarsens towards the top, wavy bedding, few Ls. clasts. Grad. lower contact.

Unit 2 (328' to 323'5"): Shale, dk. gry., calcareous, silt lenses in top of unit. Abrupt lower contact.

Unit 1 (329' to 328'): Shale, black, fissile, phosphate nodules.

CORE: HIGHBAUGH #1 STATE: KANSAS

LOCATION: SW/SE/SW SEC.21, T24S, R22E COUNTY: BOURBON



Core Description

Unit 6 (230'4" to 227'4"): Calcareous Shale, med. gry., shell hash (brachs, crinoids), Exiine?, Abrupt lower contact.

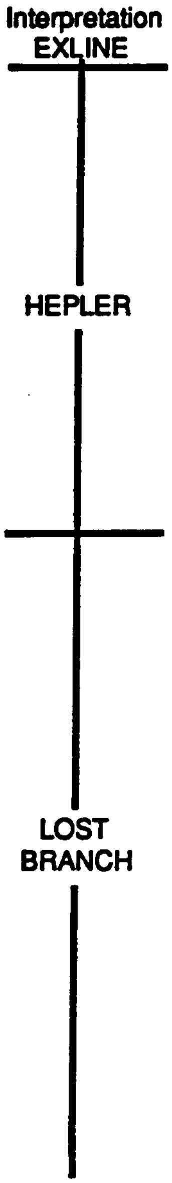
Unit 5 (231'3" to 230'4"): Silty Shale, dk.gry., limestone clasts, calcareous, wavy lam., Abrupt lower contact.

Unit 4 (231'7" to 231'3") Coal, fissile, plant frags, calcite fracture fills,. Abrupt lower contact.

Unit 3 (235'4" to 231'7"): Mudstone, med. gry., blocky, plant frags., calcareous upwards from 234', thin lam., below 234', slickensides, organics increase towards top of unit, silty towards upper contact. Grad. lower contact.

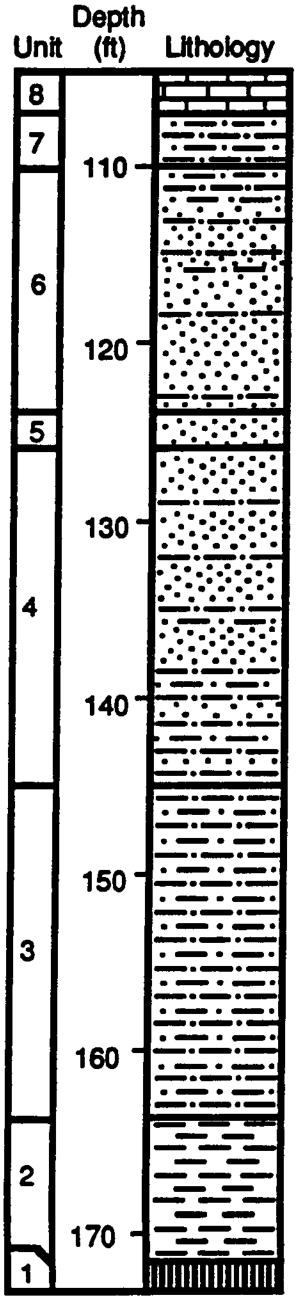
Unit 2 (245' to 235'4"): Clay Shale, dk. gry. base to med. gry., thin lam., plant frags, micaceous, Fe stains, pyrite, sparsely fossiliferous. Abrupt lower contact.

Unit 1 (246' to245'): Shale, black, thin lam., fissile, phosphate nodules, micaceous, pyrite, calcite fracture fills at base.



CORE: TROIKE #1 STATE: KANSAS

LOCATION: SE/SE/NE/SE SEC.5, T17S, R22E COUNTY: BOURBON



Core Description

Unit 8 (103' to 106'10"): Limestone, dk. gry., interlaminated shale.
Abrupt lower contact.

Unit 7 (106'10" to 110'): Siltstone, med. gry., caliche deposit near upper contact, plant frags, calcareous
Grad. lower contact.

Unit 6 (110' to 124'): Intbd. Siltstone and Sandstone, lt.gry sandstone and med.gry siltstone, Sltst. dom. upper unit., micaceous, plant frags., x-strat., Sltst. lam. near base, ripples, soft sediment deformation (drapes and folds), Abrupt grad. lower contact.

Unit 5 (124' to 126'): Med. gr. Sandstone, lt. gry., micaceous, plant frag., Grad. lower contact.

Unit 4 (126' to 145'): Intbd. Sandstone and Siltstone, lt.gry., sandstone and med. gry. siltstone. Base is Sltst. dom., x-strat. in Sst dom. sections, bedding is wavy to contorted.
Grad. lower contact.

Unit 3 (145' to 164'): Siltstone dom. with sandstone lenses, med. gry., micaceous, plant frags., wavy beds, fluid release structures, grain size inc.upwards. Grad. lower contact.

Unit 2 (164' to171'6"): Shale, med. gry to drk. gry., sltst lam. near top, plant frags., micaceous, fissile, pyrite.
Grad. lower contact.

Unit 1 (171'6" to 173'2"): Shale, black, phosphatic, pyrite, micaceous, fissile.

Interpretation

APPENDIX B:
POINT COUNT DATA

OUTCROP SAMPLES

THIN SECTION #	PuC 1.2			PuC 2.1			H-2		
	PtCt Num	PtCt%	Det%	PtCt Num	PtCt%	Det%	PtCt Num	PtCt%	Det%
MINERAL:									
QUARTZ			**82.7**			**85.6**			**92.5**
Mono	124	49.6		139	55.6		152	60.8	
Poly	10	4.0		4	1.6		8	3.2	
FELDSPARS			**1.9**			**2.4**			**.6**
K-Spar									
Microcline									
Orthoclase									
Plag-Feldspar									
Albite(Na)	3	1.2		4	1.6		1	.4	
PERTHITE	Tr								
MICAS									
Muscovite	8	3.2		10	4.0		2	.8	
Biotite	2	.8		2	.8				
Chlorite	4	1.6		Tr			2	.8	
GLAUCONITE							Tr		
CALCITE									
RUTILE									
TOURMALINE	Tr			Tr			Tr		
ROCK FRAGS:			**15.4**			**12.0**			**6.9**
VOLCANIC	1	.4							
METAMORPHIC	20	8.0		20	8.0		11	4.4	
SEDIMENTARY	4	1.6							
CHERT	Tr			Tr			1	.4	
MATRIX:									
LOW BIR	8	3.2		3	1.2		13	5.2	
HI BIR	20	8.0		28	11.2		5	2.0	
CEMENT:									
CALCITE									
SILICA				2	.8		11	4.4	
FE OXIDE	22	8.8		18	7.2		3	1.2	
OTHER:									
POROSITY:									
PRIMARY									
SECONDARY	24	9.6		20	8.0		41	16.4	
OPAQUES									
ORGANICS									
BIOLOGICS									
PYRITE									
TOTALS:	250	100		250	100		250	100	

THIN SECTION #	TP 3.8			TP 7.0			US 1		
	PtCt Num	PtCt%	Det%	PtCt Num	PtCt%	Det%	PtCt Num	PtCt%	Det%
MINERAL:									
QUARTZ			**87.5**			**81.1**			**86.3**
Mono	115	46.0		121	48.4		108	43.2	
Poly	4	1.6		12	4.8		5	2.0	
FELDSPARS			**2.9**			**1.2**			**6.1**
K-Spar									
Microcline									
Orthoclase	2	.8					3	1.2	
Plag-Feldspar									
Albite(Na)	2	.8		2	.8		5	2.0	
PERTHITE									
MICAS									
Muscovite	15	6.0		10	4.0		4	1.6	
Biotite	7	2.8		2	.8		4	1.6	
Chlorite	4	1.6		3	1.2		Tr		
GLAUCONITE							Tr		
CALCITE									
RUTILE									
TOURMALINE							Tr		
ROCK FRAGS:			**9.6**			**18.3**			**7.6**
VOLCANIC									
METAMORPHIC	13	5.2		27	10.8		10	4.0	
SEDIMENTARY	Tr								
CHERT				2	.8				
MATRIX:									
LOW BIR	44	17.6		3	1.2				
HI BIR	25	10.0		18	7.2		20	8.0	
CEMENT:									
CALCITE							61	24.4	
SILICA				2	.8		Tr		
FE OXIDE	13	5.2		28	11.2		14	5.6	
OTHER:									
POROSITY:									
PRIMARY									
SECONDARY	4	1.6		20	8.0		6	2.4	
OPAQUES	2	.8					10	4.0	
ORGANICS									
BIOLOGICS									
PYRITE									
TOTALS:	250	100		250	100		250	100	

THIN SECTION #	PC 5.6			PC 8.0			PC 8.3		
	PtCt Num	PtCt%	Det%	PtCt Num	PtCt%	Det%	PtCt Num	PtCt%	Det%
MINERAL:									
QUARTZ			**74.5**			**81.9**			**93.2**
Mono	125	50.0		128	51.2		130	52.0	
Poly	12	4.8		8	3.2		7	2.8	
FELDSPARS			**3.8**			**4.8**			**2.7**
K-Spar									
Microcline									
Orthoclase	3	1.2		4	1.6		2	.8	
Plag-Feldspar									
Albite(Na)	4	1.6		4	1.6		2	.8	
PERTHITE				Tr			Tr		
MICAS									
Muscovite	4	1.6		10	4.0		14	5.6	
Biotite	Tr			4	1.6		13	5.2	
Chlorite	Tr			2	.8		1	.4	
GLAUCONITE									
CALCITE									
RUTILE									
TOURMALINE							Tr		
ROCK FRAGS:			**21.7**			**13.3**			**4.1**
VOLCANIC	10	4.0							
METAMORPHIC	26	10.4		19	7.6		6	2.4	
SEDIMENTARY				1	.4				
CHERT	4	1.6		2	.8		Tr		
MATRIX:									
LOW BIR	8	3.2		16	6.4		12	4.8	
HI BIR	5	2.0		23	9.2		48	19.2	
CEMENT:									
CALCITE									
SILICA	Tr			Tr			Tr		
FE OXIDE	21	8.4		17	6.8		10	4.0	
OTHER:									
POROSITY:									
PRIMARY									
SECONDARY	28	11.2		12	4.8		5	2.0	
OPAQUES							Tr		
ORGANICS									
BIOLOGICS									
PYRITE									
TOTALS:	250	100		250	100		250	100	

THIN SECTION #	EP 0.1			EP 0.9			EP 1.5		
	PtCt Num	PtCt%	Det%	PtCt Num	PtCt%	Det%	PtCt Num	PtCt%	Det%
MINERAL:									
QUARTZ			98.2			94.8			90.6
Mono	157	62.8		142	56.8		118	47.2	
Poly	9	3.6		5	2.0		8	3.2	
FELDSPARS			.0			2.6			2.2
K-Spar									
Microcline									
Orthoclase				3	1.2		Tr		
Plag-Feldspar									
Albite(Na)	1	.4		1	.4		3	1.2	
PERTHITE	Tr			Tr					
MICAS									
Muscovite	3	1.2		3	1.2		2	.8	
Biotite	2	.8		Tr			1	.4	
Chlorite				Tr			1	.4	
GLAUCONITE									
CALCITE									
RUTILE									
TOURMALINE	Tr						Tr		
ROCK FRAGS:			1.2			2.6			7.2
VOLCANIC									
METAMORPHIC	2	.8		3	1.2		7	2.8	
SEDIMENTARY									
CHERT	Tr			1	.4		3	1.2	
MATRIX:									
LOW BIR	4	1.6		5	2.0		Tr		
HI BIR	13	5.2		7	2.8		34	13.6	
CEMENT:									
CALCITE				52	20.8		45	18.0	
SILICA	16	6.4		1	.4		Tr		
FE OXIDE	5	2.0		22	8.8		21	8.4	
OTHER:									
POROSITY:									
PRIMARY									
SECONDARY	35	14.0		5	2.0		7	2.8	
OPAQUES	3	1.2		Tr			Tr		
ORGANICS									
BIOLOGICS									
PYRITE									
TOTALS:	250	100		250	100		250	100	

THIN SECTION #	EP 4.2			EP 4.3			EP 5.8		
	PtCT Num	PtCt%	Det%	PtCt Num	PtCt%	Det%	PtCt Num	PtCt%	Det%
MINERAL:									
QUARTZ			**93.6**			**94.6**			**95.7**
Mono	168	67.2		138	55.2		173	69.2	
Poly	7	2.8		3	1.2		5	2.0	
FELDSPARS			**1.6**			**2.7**			**1.1**
K-Spar									
Microcline	Tr			Tr			Tr		
Orthoclase				2	.8				
Plag-Feldspar									
Albite(Na)	3	1.2		2	.8		2	.8	
PERTHITE	Tr			Tr			Tr		
MICAS									
Muscovite	2	.8					2	.8	
Biotite	Tr								
Chlorite	Tr			Tr					
GLAUCONITE				Tr					
CALCITE				4	1.6				
RUTILE									
TOURMALINE				Tr					
ROCK FRAGS:			**.0**			**2.7**			**.0**
VOLCANIC									
METAMORPHIC	9	3.6		4	1.6		6	2.4	
SEDIMENTARY									
CHERT									
MATRIX:									
LOW BIR	2	.8					8	3.2	
HI BIR	17	6.8					7	2.8	
CEMENT:									
CALCITE	15	6.0		93	37.2				
SILICA	1	.4					14	5.6	
FE OXIDE	2	.8		2	.8		Tr		
OTHER:									
POROSITY:									
PRIMARY									
SECONDARY	22	8.8		2	.8		31	12.4	
OPAQUES	2	.8		Tr			2	.8	
ORGANICS									
BIOLOGICS									
PYRITE									
TOTALS:	250	100		250	100		250	100	

THIN SECTION #	SEP 1.5			SEP 3.3			SEP 3.6		
	PtCt Num	PtCt%	Det%	PtCt Num	PtCt%	Det%	PtCt Num	PtCt%	Det%
MINERAL:									
QUARTZ			**93.3**			**87.6**			**90.1**
Mono	120	48.0		135	54.0		136	54.4	
Poly	5	2.0		6	2.4		9	3.6	
FELDSPARS			**.0**			**1.2**			**4.3**
K-Spar									
Microcline	Tr						Tr		
Orthoclase	Tr			2	.8		3	1.2	
Plag-Feldspar									
Albite(Na)	Tr			Tr			4	1.6	
PERTHITE	Tr			Tr					
MICAS									
Muscovite	2	.8		1	.4		1	.4	
Biotite	1	.4							
Chlorite									
GLAUCONITE									
CALCITE									
RUTILE									
TOURMALINE				Tr			Tr		
ROCK FRAGS:			**6.7**			**11.2**			**5.6**
VOLCANIC									
METAMORPHIC	8	3.2		16	6.4		8	3.2	
SEDIMENTARY									
CHERT	1	.4		2	.8		1	.4	
MATRIX:									
LOW BIR				6	2.4		12	4.8	
HI BIR				13	5.2				
CEMENT:									
CALCITE	61	24.4							
SILICA	1	.4		4	1.6		8	3.2	
FE OXIDE	36	14.4		13	5.2		12	4.8	
OTHER:									
POROSITY:									
PRIMARY									
SECONDARY	15	6.0		52	20.8		56	22.4	
OPAQUES	Tr			Tr					
ORGANICS									
BIOLOGICS									
PYRITE									
TOTALS:	250	100		250	100		250	100	

THIN SECTION #	SEP 4.5			UE .1			UE 3.9		
	PtCt Num	PtCt%	Det%	PtCt Num	PtCt%	Det%	PtCt Num	PtCt%	Det%
MINERAL:									
QUARTZ			**91.7**			**82.8**			**86.8**
Mono	144	57.6		123	49.2		147	58.8	
Poly	10	4.0		2	.8		11	4.4	
FELDSPARS			**.0**			**6.6**			**2.2**
K-Spar									
Microcline									
Orthoclase	Tr			5	2.0		1	.4	
Plag-Feldspar									
Albite(Na)	2	.8		5	2.0		3	1.2	
PERTHITE				Tr					
MICAS									
Muscovite	Tr			2	.8		7	2.8	
Biotite				2	.8		Tr		
Chlorite				1	.4		2	.8	
GLAUCONITE									
CALCITE									
RUTILE				Tr					
TOURMALINE	Tr			Tr					
ROCK FRAGS:			**7.1**			**10.6**			**11.0**
VOLCANIC				Tr			4	1.6	
METAMORPHIC	12	4.8		15	6.0		16	6.4	
SEDIMENTARY									
CHERT	Tr			1	.4				
MATRIX:									
LOW BIR	7	2.8		3	1.2		7	2.8	
HI BIR	11	4.4		30	12.0		2	.8	
CEMENT:									
CALCITE				39	15.6		2	.8	
SILICA	8	3.2		Tr					
FE OXIDE	12	4.8		19	7.6		15	6.0	
OTHER:									
POROSITY:									
PRIMARY									
SECONDARY	44	17.6		3	1.2		33	13.2	
OPAQUES				Tr			Tr		
ORGANICS									
BIOLOGICS									
PYRITE									
TOTALS:	250	100		250	100		250	100	

THIN SECTION #	PC 1.3			PC 2.8			PC 4.3		
	PtCt Num	PtCt%	Det%	PtCt Num	PtCt%	Det%	PtCt Num	PtCt%	Det%
MINERAL:									
QUARTZ			**98.0**			**93.5**			**84.4**
Mono	91	36.4		110	44.0		113	45.2	
Poly	3	1.2		6	2.4		6	2.4	
FELDSPARS			**.0**			**3.2**			**2.1**
K-Spar									
Microcline									
Orthoclase				2	.8				
Plag-Feldspar									
Albite(Na)	Tr			2	.8		3	1.2	
PERTHITE									
MICAS									
Muscovite	20	8.0		16	6.4		11	4.4	
Biotite	14	5.6		9	3.6		6	2.4	
Chlorite	4	1.6		2	.8		Tr		
GLAUCONITE									
CALCITE									
RUTILE									
TOURMALINE				Tr			Tr		
ROCK FRAGS:			**2.0**			**3.2**			**13.5**
VOLCANIC									
METAMORPHIC	2	.8		4	1.6		19	7.6	
SEDIMENTARY									
CHERT									
MATRIX:									
LOW BIR				3	1.2		10	4.0	
HI BIR	103	41.2		54	21.6		28	11.2	
CEMENT:									
CALCITE									
SILICA									
FE OXIDE	5	2.0		37	14.8		51	20.4	
OTHER:									
POROSITY:									
PRIMARY									
SECONDARY	5	2.0		4	1.6		3	1.2	
OPAQUES	3	1.2		1	.4				
ORGANICS									
BIOLOGICS									
PYRITE									
TOTALS:	250	100		250	100		250	100	

CORE SAMPLES

THIN SECTION #	TR131'8"			TR127'3"			TR124'3"		
	PtCtNum	PtCt%	Det%	PtCtNum	PtCt%	Det%	PtCtNum	PtCt%	Det%
MINERAL:									
QUARTZ			**88.9**			**86.0**			**85.5**
Mono	137	54.8		140	56.0		131	52.4	
Poly	8	3.2		8	3.2		10	4.0	
FELDSPARS			**3.1**			**3.5**			**2.4**
K-Spar									
Microcline									
Orthoclase									
Plag-Feldspar									
Albite(Na)	5	2.0		4	1.6		4	1.6	
PERTHITE	Tr			2	.8		Tr		
MICAS									
Muscovite	11	4.4		12	4.8		10	4.0	
Biotite	Tr			8	3.2		3	1.2	
Chlorite	4	1.6		5	2.0		Tr		
GLAUCONITE				1	.4		Tr		
CALCITE									
RUTILE	Tr								
TOURMALINE	Tr								
ROCK FRAGS:			**8.0**			**10.5**			**12.1**
VOLCANIC									
METAMORPHIC	9	3.6		14	5.6		10	4.0	
SEDIMENTARY	4	1.6		4	1.6		6	2.4	
CHERT	Tr			Tr			4	1.6	
MATRIX:									
LOW BIR	27	10.8		15	6.0		18	7.2	
HI BIR	5	2.0		8	3.2		6	2.4	
CEMENT:									
CALCITE	20	8.0		10	4.0		14	5.6	
SILICA							2	.8	
FE OXIDE									
OTHER:									
POROSITY:									
PRIMARY									
SECONDARY	18	7.2		17	6.8		29	11.6	
OPAQUES	2	.8		2	.8		3	1.2	
ORGANICS									
BIOLOGICS									
PYRITE									
TOTALS:	250	100		250	100		250	100	

THIN SECTION #	TR120'10"			TR115'			TR110'3"		
	PtCtNum	PtCt%	Det%	PtCtNum	PtCt%	Det%	PtCtNum	PtCt%	Det%
MINERAL:									
QUARTZ			**88.0**			**87.6**			**96.0**
Mono	157	62.8		130	52.0		117	46.8	
Poly	5	2.0		4	1.6		2	.8	
FELDSPARS			**3.3**			**2.6**			**1.6**
K-Spar									
Microcline									
Orthoclase									
Plag-Feldspar									
Albite(Na)	6	2.4		4	1.6		2	.8	
PERTHITE	Tr								
MICAS									
Muscovite	8	3.2		11	4.4		7	2.8	
Biotite	3	1.2		3	1.2		6	2.4	
Chlorite	2	.8		2	.8		1	.4	
GLAUCONITE	Tr			Tr					
CALCITE									
RUTILE							Tr		
TOURMALINE							Tr		
ROCK FRAGS:			**8.7**			**9.8**			**2.4**
VOLCANIC									
METAMORPHIC	12	4.8		10	4.0	5.9	3	1.2	
SEDIMENTARY	2	.8		3	1.2	1.8			
CHERT	2	.8		2	.8	1.2			
MATRIX:									
LOW BIR	15	6.0		17	6.8		12	4.8	
HI BIR	13	5.2		30	12.0		7	2.8	
CEMENTS:									
CALCITE	12	4.8		8	3.2		79	31.6	
SILICA	2	.8		2	.8				
FE OXIDE							11	4.4	
OTHER:									
POROSITY:									
PRIMARY									
SECONDARY	9	3.6		23	9.2		2	.8	
OPAQUES	2	.8		1	.4		1	.4	
ORGANICS									
BIOLOGICS									
PYRITE									
TOTALS:	250	100		250	100		250	100	

THIN SECTION #	G396.5'			EM164'3"			NE314'8"		
	PtCtNum	PtCt%	Det%	PtCtNum	PtCt%	Det%	PtCtNum	PtCt%	Det%
MINERAL:									
QUARTZ			**98.2**			**94.9**			**96.0**
Mono	106	42.4		121	48.4		90	36.0	
Poly	3	1.2		9	3.6		4	1.6	
FELDSPARS			**0**			**.7**			**.0**
K-Spar									
Microcline									
Orthoclase									
Plag-Feldspar									
Albite(Na)	Tr			1	.4		1	.4	
PERTHITE				Tr					
MICAS									
Muscovite	7	2.8		17	6.8		5	2.0	
Biotite	2	.8		6	2.4		1	.4	
Chlorite	3	1.2		6	2.4		1	.4	
GLAUCONITE									
CALCITE									
RUTILE	Tr								
TOURMALINE	2	.8		Tr			Tr		
ROCK FRAGS:			**1.8**			**4.4**			**3.1**
VOLCANIC									
METAMORPHIC	1	.4		4	1.6		3	1.2	
SEDIMENTARY				2	.8				
CHERT	1	.4		Tr					
MATRIX:									
LOW BIR				17	6.8		3	1.2	
HI BIR				40	16.0		60	24.0	
CEMENTS:									
CALCITE	114	45.6		12	4.8		37	14.8	
SILICA									
FE OXIDE									
OTHER:									
POROSITY:									
PRIMARY									
SECONDARY	2	.8		14	5.6		16	6.4	
OPAQUES	2	.8		2	.8		2	.8	
ORGANICS	4	1.6							
BIOLOGICS							15	6.0	
PYRITE	3	1.2					12	4.8	
TOTALS:	250	100		250	100		250	100	

APPENDIX C:

WELL LOG DATA

Explanation of Kansas Code:

QQQSNTSRE = 9 Digit Well Location

QQQ = Sectioal Quadrants

SN = Section Number

TS = Township South

RE = Range East

HEPLER WELL LOG DATA

KANSAS CODE	NUY CRK TOP	MD CITY BOT	UNIT THICK	UNIT BREAK	UPPER UNIT	LOWER UNIT	HEPLER "C" SS THICK
TOWNSHIP 16S							
421231616	1013	878	135	998	120	15	4
001021618	750	617	133	719	102	31	8
004281618	700	564	136	678	114	22	11
442251620	638	491	147	602	111	36	14
001111621	528	394	134	496	102	32	7
003121621	529	400	129	504	104	25	7
001241621	523	390	133	497	107	26	6
000251621	484	352	132	455	103	29	8
000261621	499	370	129	472	102	27	8
000351621	489	360	129	463	103	26	8
003311622	503	374	129	476	102	27	9
003311622	497	367	130	468	101	29	8
003311622	524	398	126	498	100	26	8
004311622	508	381	127	482	101	26	7
114311622	516	388	128	490	102	26	8
000221623	296	153	143	264	111	32	0
000361623	370	222	148	338	116	32	9
004111624	416	258	158	364	106	52	11
002201624	402	262	140	368	106	34	6
000311624	321	188	133	288	100	33	9
000311624	367	236	131	332	96	35	8
000311624	304	176	128	274	98	30	8
000311624	258	136	122	226	90	32	9
000311624	307	154	153	274	120	33	8
000311624	300	147	153				8
000311624	302	159	143	272	113	30	6
000341624	300	160	140	266	106	34	9
TOWNSHIP 17S							
000221706	1782	1724	58	1766	42	16	6
022251708	2196	2003	193				0
033071712	1640	1530	110				0
034051717	789	643	146				8
042121720	430	296	134	400	104	30	8
000251720	516	322	194	488	166	28	10
042071721	451	324	127	424	100	27	7
321101721	460	332	128	434	102	26	7
044141721	406	276	130				0
012151721	446	324	122	418	94	28	9
121151721	390	268	122	368	100	22	7
002161721	334	212	122	310	98	24	8
001201721	445	318	127	418	100	27	10
343261721	312	198	114	290	92	22	12

KANSAS CODE	NUY CRK TOP	MD CITY BOT	UNIT THICK	UNIT BREAK	UPPER UNIT	LOWER UNIT	HEPLER "C" SS THICK
333011722	334	200	134	310	110	24	6
044031722	375	244	131	352	108	23	12
113041722	508	379	129	482	103	26	11
000051722	496	356	140	474	118	22	6
002051722	511	386	125	486	100	25	6
042061722	498	375	123	476	101	22	7
001061722	486	360	126	448	88	38	6
001121722	343	192	151	314	122	29	7
000131722	382	252	130	360	108	22	9
000231722	324	193	131	300	107	24	6
000251722	352	228	124	328	100	24	8
011311722	310	184	126	284	100	26	8
002111723	372	219	153	339	120	33	9
121201723	333	198	135	306	108	27	8
000221723	270	118	152	240	122	30	11
014221723	229	76	153	198	122	31	7
000241723	296	178	118	263	85	33	8
000061724	400	232	168	366	134	34	9
000061724	404	240	164	372	132	32	9
000061724	382	231	151	350	119	32	10
002111724	340	197	143	305	108	35	7
241121724	432	282	150	394	112	38	6
313301725	350	207	143	320	113	30	4
TOWNSHIP 18S							
014191801	2670	2452	218	2640	188	30	22
024341802	2330	2192	138	2308	116	22	17
022071807	1818	1750	68	1780	30	38	10
444321812	1476	1360	116	1420	60	56	13
423061816	917	782	135	900	118	17	0
011061817	809	664	145	792	128	17	8
000121820	488	350	138	460	110	28	7
114131820	513	374	139	486	112	27	5
001241820	498	352	146	470	118	28	7
002011821	324	197	127	296	99	28	11
004041821	443	310	133	417	107	26	6
004071821	467	331	136	438	107	29	21
000171821	381	244	137	358	114	23	12
003231821	313	182	131	280	98	33	29
001041822	258	124	134	218	94	40	0
001041822	252	120	132	224	104	28	10
001101822	262	129	133	234	105	28	12
000121822	238	102	136	204	102	34	11
344011823	251	94	157	212	118	39	10
001041824	399	198	201	306	108	93	6
221061824	297	138	159	260	122	37	6

KANSAS CODE	NUY CRK TOP	MD CITY BOT	UNIT THICK	UNIT BREAK	UPPER UNIT	LOWER UNIT	HEPLER "C" SS THICK
003161824	279	125	154	250	125	29	3
323161824	296	144	152	246	102	50	34
012181824	243	92	151	214	122	29	2
321211824	263	114	149	236	122	27	4
TOWNSHIP 19S							
311201906	1926	1867	59	1910	43	16	6
111201908	1938	1850	88	1912	62	26	7
114231910	1628	1518	110				0
232021912	1396	1277	119				0
314041912	1464	1353	111				0
212261912	1337	1211	126	1328	117	9	2
334241913	1256	1151	105	1240	89	16	11
114271913	1290	1168	122	1263	95	27	6
413281913	1252	1123	129	1238	115	14	7
024341913	1252	1129	123	1230	101	22	8
442011914	1168	1038	130	1156	118	12	8
331271914	1204	1072	132				21
114301914	1214	1084	130				22
112341914	1191	1058	133	1176	118	15	10
221051915	1163	1034	129	1141	107	22	13
331061915	1154	1024	130	1144	120	10	8
112341917	920	755	165	884	129	36	9
031111918	687	535	152	668	133	19	18
013241921	520	371	149	491	120	29	13
000141922	254	112	142	222	110	32	9
000351922	346	178	168	312	134	34	22
000011923	176	28	148	146	118	30	4
TOWNSHIP 20S							
023152005	2102	2003	99	2091	88	11	6
334362008	1986	1878	108	1966	88	20	6
014102010	1706	1596	110				0
014182010	1868	1761	107				0
111202010	1892	1788	104	1864	76	28	0
443302010	1937	1832	105	1918	86	19	1
331322010	1925	1812	113	1888	76	37	34
114152011	1542	1419	123				0
224082012	1442	1324	118	1406	82	36	10
024172012	1485	1365	120	1440	75	45	14
224012013	1190	1071	119				10
132272013	1246	1106	140				18
323362013	1216	1077	139	1204	127	12	5
331092014	1150	1017	133	1138	121	12	11
441162014	1144	1012	132	1130	118	14	10
031252014	1067	931	136	1052	121	15	12

KANSAS CODE	NUY CRK TOP	MD CITY BOT	UNIT THICK	UNIT BREAK	UPPER UNIT	LOWER UNIT	HEPLER "C" SS THICK
334032015	1098	956	142	1086	130	12	12
114332015	1036	886	150	1018	132	18	8
441192017	950	798	152	928	130	22	22
144082019	583	431	152	552	121	31	11
001252019	567	406	161	540	134	27	8
433152019	657	478	179	612	134	45	26
313132020	448	293	155	418	125	30	20
324132020	476	321	155	444	123	32	16
324132020	432	278	154	404	126	28	25
000272021	364	210	154	326	116	38	11
013272021	394	238	156	364	126	30	14
122272021	361	206	155	332	126	29	13
222272021	355	200	155	326	126	29	10
314272021	375	204	171	343	139	32	13
131332021	390	236	154	360	124	30	22
000162022	338	188	150	306	118	32	14
000162022	313	158	155	278	120	35	10
111222022	285	132	153	251	119	34	9
333042023	224	76	148	198	122	26	6
443302024	182	46	136				14
TOWNSHIP 21S							
043172105	1541	1440	101	1522	82	19	13
414242106	2284	2211	73	2270	59	14	9
443362109	1868	1767	101				0
111082110	1814	1705	109	1776	71	38	13
034182110	1844	1738	106	1826	88	18	8
211252111	1556	1436	120				0
221032112	1420	1302	118	1378	76	42	12
022322112	1476	1352	124				0
332012113	1210	1086	124	1183	97	27	9
111102113	1234	1104	130	1182	78	52	13
144112113	1280	1139	141	1270	131	10	7
142142113	1306	1168	138	1280	112	26	14
223202113	1388	1253	135				0
422232113	1240	1101	139	1224	123	16	8
333242113	1256	1113	143	1238	125	18	11
441252113	1247	1109	138	1236	127	11	7
122262113	1255	1115	140	1240	125	15	0
232352113	1290	1156	134	1276	120	14	8
444362113	1266	1137	129	1250	113	16	11
442032114	1124	986	138	1108	122	16	8
231102114	1128	994	134	1114	120	14	8
324112114	1063	923	140	1045	122	18	9
333162114	1208	1074	134	1198	124	10	14
123192114	1220	1085	135	1205	120	15	7

KANSAS CODE	NUY CRK TOP	MD CITY BOT	UNIT THICK	UNIT BREAK	UPPER UNIT	LOWER UNIT	HEPLER "C" SS THICK
441222114	1144	1006	138	1130	124	14	8
142302114	1238	1102	136	1222	120	16	10
441312114	1242	1112	130	1214	102	28	10
423322114	1224	1092	132	1210	118	14	10
131342114	1192	1058	134	1176	118	16	10
111112115	994	846	148	974	128	20	12
122162115	950	808	142	936	128	14	8
331212115	1000	856	144	980	124	20	8
332292115	1036	896	140	1022	126	14	7
414312115	1066	925	141	1050	125	16	6
334332115	1018	876	142	1000	124	18	10
113112116	898	747	151	878	131	20	12
223242117	758	602	156	726	124	32	12
004032119	544	382	162	512	130	32	6
000042119	580	408	172				0
000122119	504	320	184	462	142	42	13
111132119	490	320	170	454	134	36	7
001222119	572	438	134	548	110	24	15
113142120	571	403	168	533	130	38	29
311142120	571	412	159	533	121	38	28
000152120	586	436	150	554	118	32	28
000152120	568	418	150	536	118	32	25
141152120	582	430	152	550	120	32	28
223152120	570	418	152	540	122	30	25
000162120	590	436	154	536	100	54	20
221162120	566	412	154	536	124	30	17
001042121	368	206	162	336	130	32	2
001042121	368	204	164	337	133	31	2
323042121	365	201	164	334	133	31	7
341042121	368	204	164	336	132	32	4
021082121	406	256	150	376	120	30	6
212362121	245	86	159	214	128	31	22
TOWNSHIP 22S							
441162203	2474	2381	93	2456	75	18	11
332222204	2348	2249	99	2340	91	8	5
443012210	1659	1500	159				0
021102210	1876	1770	106	1872	102	4	1
122112210	1683	1575	108				0
333172210	1973	1866	107				0
123292210	1963	1853	110	1955	102	8	2
113072211	1700	1589	111				0
412272211	1566	1443	123				0
042322211	1548	1423	125	1530	107	18	7
233112213	1285	1154	131	1250	96	35	14
113212213	1336	1201	135	1316	115	20	12

KANSAS CODE	NUY CRK TOP	MD CITY BOT	UNIT THICK	UNIT BREAK	UPPER UNIT	LOWER UNIT	HEPLER "C" SS THICK
114262213	1272	1136	136	1250	114	22	12
133102214	1158	1023	135	1144	121	14	6
123272214	1128	989	139	1110	121	18	11
112132215	934	780	154	916	136	18	3
242142215	979	826	153	954	128	25	10
442252215	850	693	157	830	137	20	13
441292215	1052	903	149	1030	127	22	8
444362215	853	701	152	834	133	19	11
221112216	817	661	156	798	137	19	9
142192216	818	662	156	794	132	24	8
032212216	796	650	146	784	134	12	8
124212216	795	647	148	780	133	15	10
013222216	780	640	140				0
023272216	778	624	154	760	136	18	16
014282216	781	626	155	760	134	21	11
442282216	780	626	154	760	134	20	13
033302216	842	685	157	820	135	22	5
113312216	870	714	156	847	133	23	11
013292217	755	598	157	729	131	26	14
343292217	750	592	158	724	132	26	11
323282218	621	462	159	598	136	23	10
244292218	620	457	163	590	133	30	10
422082219	611	450	161	572	122	39	28
144092219	628	465	163	592	127	36	25
433152219	653	462	191	604	142	49	22
000162219	618	449	169	576	127	42	29
024162219	609	443	166	568	125	41	31
003212219	638	450	188	600	150	38	20
001222219	568	404	164	536	132	32	11
044012221	247	86	161	204	118	43	38
334182222	269	105	164	236	131	33	23
TOWNSHIP 23S							
312042310	1821	1701	120				0
223132310	1676	1550	126				0
000192310	1922	1814	108				0
422222310	1715	1594	121				0
002032311	1524	1398	126				0
314162311	1576	1450	126				0
000092312	1315	1183	132				0
000202312	1370	1242	128				0
044012313	1212	1077	135	1198	121	14	8
021152313	1192	1056	136	1180	124	12	5
122232313	1207	1076	131	1190	114	17	8
024293313	1242	1178	64	1206	28	36	10
331092314	1109	973	136	1092	119	17	9

KANSAS CODE	NUY CRK TOP	MD CITY BOT	UNIT THICK	UNIT BREAK	UPPER UNIT	LOWER UNIT	HEPLER "C" SS THICK
431242314	1015	873	142				0
343092315	986	834	152	958	124	28	12
441092315	963	815	148	944	129	19	11
001192315	982	890	92	962	72	20	12
014312315	982	838	144	964	126	18	8
011012316	730	570	160	704	134	26	14
121062316	826	675	151	808	133	18	12
434102316	733	575	158	710	135	23	11
033112316	733	582	151	708	126	25	13
413112316	732	582	150	708	126	24	14
003122316	713	558	155	689	131	24	22
343122316	716	558	158	690	132	26	24
002132316	715	554	161	686	132	29	12
044132316	708	542	166	678	136	30	14
332132316	711	550	161	684	134	27	12
131142316	732	574	158	708	134	24	15
144142316	715	556	159	682	126	33	14
002332316	823	666	157	800	134	23	18
002302317	682	522	160	657	135	25	10
041062318	618	451	167				18
142272318	594	420	174	562	142	32	10
141292318	568	408	160	536	128	32	8
243042319	510	343	167	476	133	34	15
331042321	388	216	172	350	134	38	22
233042321	375	198	177	336	138	39	20
311042321	394	214	180	354	140	40	14
242052321	370	204	166	344	140	26	12
114092321	319	148	171				16
433282321	275	114	161	238	124	37	24
001342321	252	93	159	213	120	39	16
TOWNSHIP 24S							
001112402	2648	2563	85	2612	49	36	14
313342409	1916	1808	108				3
231082411	1630	1507	123				6
134172412	1307	1168	139	1293	125	14	7
013132415	926	778	148	904	126	22	12
332332415	924	766	158	898	132	26	8
000022416	792	636	156	770	134	22	12
313022418	544	378	166	511	133	33	26
114332420	407	206	201	366	160	41	18
132342420	402	220	182	360	140	42	28
241352420	402	214	188	257	43	145	35
444252421	240	117	123	215	98	25	24
242262421	260	115	145	232	117	28	26
411362421	224	109	115	200	91	24	22

KANSAS CODE	NUY CRK TOP	MD CITY BOT	UNIT THICK	UNIT BREAK	UPPER UNIT	LOWER UNIT	HEPLER "C" SS THICK
433082422	230	94	136	200	106	30	19
234142422	178	73	105				15
133302422	238	113	125				17
322142424	183	98	85	149	51	34	17
TOWNSHIP 25S							
332142501	2800	2748	52				6
423252504	2284	2193	91				0
221012510	1531	1414	117	1490	76	41	2
333332511	1452	1314	138				0
121172512	1434	1304	130				0
231122514	992	838	154	972	134	20	10
444062516	710	555	155	690	135	20	11
132242516	617	461	156	598	137	19	5
324232517	538	381	157	532	151	6	2
343142519	440	253	187	396	143	44	22
332282519	437	259	178	390	131	47	34
442332520	397	211	186	352	141	45	21
000072521	360	206	154	326	120	34	12
421122521	260	160	100				0
111182521	348	207	141	321	114	27	14
TOWNSHIP 26S							
341032605	2240	2168	72	2218	50	22	2
323042605	2196	2114	82	2176	62	20	2
142132605	2246	2173	73	2236	63	10	6
432222607	2326	2235	91	2298	63	28	11
111262607	2287	2206	81	2280	74	7	2
341102608	2095	1996	99	2062	66	33	6
411292608	2280	2183	97	2250	67	30	8
114132609	1564	1462	102	1542	80	22	4
144232609	1640	1533	107	1608	75	32	12
333072610	1611	1510	101	1580	70	31	4
411182610	1564	1460	104				0
223242611	1328	1207	121	1316	109	12	2
321082612	1280	1186	94	1268	82	12	8
441112612	1102	970	132	1092	122	10	8
332302612	1334	1205	129	1316	111	18	0
242132614	768	647	121	746	99	22	10
142192615	867	756	111	845	89	22	11
223162616	702	577	125	684	107	18	15
000222617	412	254	158	368	114	44	30
422242617	466	326	140	430	104	36	14
331252617	464	334	130	434	100	30	18
443022618	394	225	169	354	129	40	28
222052619	418	244	174	378	134	40	26

KANSAS CODE	NUY CRK TOP	MD CITY BOT	UNIT THICK	UNIT BREAK	UPPER UNIT	LOWER UNIT	HEPLER "C" SS THICK
004232620	301	160	141				12
004182621	334	195	139	314	119	20	0
413182621	279	148	131	253	105	26	0
001282621	271	166	105				0
000192622	234	130	104				0
TOWNSHIP 27S							
242152705	2409	2356	53	2378	22	31	8
000272705	2432	2370	62				8
023282706	2354	2292	62	2342	50	12	8
221332706	2348	2268	80	2306	38	42	4
022352706	2000	1890	110				0
414202707	2342	2229	113	2320	91	22	8
424132708	1946	1795	151	1892	97	54	0
341252708	1964	1832	132	1942	110	22	0
141182709	1928	1796	132	1903	107	25	4
043062710	1686	1557	129	1636	79	50	8
013072711	1384	1251	133	1360	109	24	4
000312711	1466	1325	141	1445	120	21	8
034292713	1026	964	62	1004	40	22	12
230332713	956	902	54	936	34	20	10
314202714	800	715	85	746	31	54	16
002142715	572	468	104				11
121062716	578	480	98	550	70	28	8
000042717	547	429	118	518	89	29	6
121112718	312	172	140	300	128	12	6
131222718	324	174	150	282	108	42	8
000332719	264	90	174	220	130	44	10
242082720	296	146	150	256	110	40	12
112122721	150	54	96	76	22	74	18
424052722	174	89	85	109	20	65	26
TOWNSHIP 28S							
000012805	2404	2334	70	2365	31	39	12
112052805	2436	2384	52				0
242092806	2310	2258	52	2288	30	22	5
222152806	2256	2196	60	2234	38	22	6
221022807	2306	2196	110				0
332032807	2357	2244	113				0
314242808	2071	1985	86	2060	75	11	4
444262812	1061	1014	47	1040	26	21	26
000032813	955	908	47	932	24	23	18
212262813	810	778	32	790	12	20	8
431342813	842	810	32	824	14	18	12
000042815	568	526	42	554	28	14	6
114242815	485	452	33	466	14	19	6

KANSAS CODE	NUY CRK TOP	MD CITY BOT	UNIT THICK	UNIT BREAK	UPPER UNIT	LOWER UNIT	HEPLER "C" SS THICK
001192816	506	472	34	491	19	15	4
111232816	500	450	50	476	26	24	9
111162817	478	418	60	440	22	38	12
433042818	384	346	38	352	6	32	33
222242818	284	244	40				28
343362818	270	222	48	230	8	40	22
334102819	245	140	105				10
331192819	276	230	46	238	8	38	28
TOWNSHIP 29S							
000022904	2421	2415	6				0
334232904	2562	2556	6				0
011182905	2556	2534	22				0
003292905	2462	2443	19				6
214162906	2374	2336	38				6
312202906	2386	2360	26				18
023102907	2397	2368	29				20
003142907	2394	2368	26				22
000192908	2266	2238	28				23
114192908	2246	2218	28				21
231342909	1776	1743	33				30
031132910	1501	1444	57				42
421342910	1438	1406	32				0
314122912	1094	1059	35				16
000202913	1153	1130	23				14
022232913	865	843	22				18
332012914	567	541	26				20
024112916	376	344	32				31
001122916	386	350	36				32
311122916	328	295	33				30
134242917	352	305	47				38
341302917	359	330	29				27
311362917	382	344	38				35
TOWNSHIP 30S							
441023003	2768	2752	16				4
312103003	2502	2423	79				0
032243003	2739	2722	17				8
332013004	2472	2457	15				10
312113004	2466	2450	16				11
244133004	2534	2520	14				10
000153004	2500	2485	15				13
004233004	2557	2541	16				6
423333004	2533	2521	12				10
114333005	2492	2479	13				9
111193006	2430	2418	12				10

KANSAS CODE	NUY CRK TOP	MD CITY BOT	UNIT THICK	UNIT BREAK	UPPER UNIT	LOWER UNIT	HEPLER "C" SS THICK
342313006	2495	2488	7				4
321123007	2241	2221	20				18
443103008	2305	2286	19				15
033253008	2035	2022	13				10
112093009	1916	1886	30				25
324093009	2036	2002	34				16
412353009	1781	1768	13				12
443143010	1440	1420	20				11
111263010	1466	1445	21				10
043303011	1366	1346	20				10
444153012	1016	990	26				13
131183013	934	909	25				10
421333013	896	874	22				10
441343014	682	664	18				14
000083015	680	661	19				12
244253016	386	361	25				18
332263016	340	320	20				15
243013017	405	386	19				28
321063017	330	301	29				6
311223017	408	384	24				22
131303017	297	274	23				3
134323019	201	158	43				22
TOWNSHIP 31S							
021153103	2784	2775	9				3
022293113	2780	2773	7	2775	2	5	3
213363104	2614	2550	64	2557	7	57	6
241203105	2454	2416	38	2430	14	24	3
113213105	2620	2550	70	2580	30	40	9
002363105	2598	2544	54	2550	6	48	6
034363105	2659	2598	61	2608	10	51	9
444073106	2492	2448	44	2468	20	24	13
223143107	2434	2399	35				9
233033108	2172	2158	14				2
124163108	2286	2216	70	2238	22	48	6
322163109	1754	1743	11				3
314173109	1780	1768	12				3
113103110	1452	1434	18	1442	8	10	7
143153111	1312	1294	18	1302	8	10	6
412173113	1007	986	21	993	7	14	7
000233113	832	773	59	818	45	14	11
032203114	732	714	18	719	5	13	4
441263114	720	701	19				10
113143115	446	428	18				10
341233115	474	457	17				8
000023116	315	290	25				8

KANSAS CODE	NUY CRK TOP	MD CITY BOT	UNIT THICK	UNIT BREAK	UPPER UNIT	LOWER UNIT	HEPLER "C" SS THICK
234233116	326	303	23				14
244243116	408	384	24	388	4	20	14
000053117	412	384	28	392	8	20	11
133303117	291	264	27	271	7	20	18
TOWNSHIP 32S							
344023203	2741	2721	20	2734	13	7	0
314093203	2763	2730	33	2746	16	17	0
332153204	2593	2580	13				6
012223204	2593	2576	17				8
003133205	2586	2566	20				0
321333205	2630	2606	24				3
143103207	2378	2354	24	2363	9	15	5
022043208	2240	2230	10				4
411183208	1000	982	18				5
211343208	1871	1852	19				7
323173209	1760	1754	6				2
243293209	1771	1759	12				2
113023210	1466	1452	14				4
444043210	1496	1482	14				3
004283210	1432	1418	14				8
214063211	1340	1322	18				3
124083211	1344	1324	20				5
121173211	1357	1341	16				4
312183211	1358	1340	18	1346	6	12	4
114133212	1063	1044	19	1051	7	12	6
032143212	886	870	16				9
441063213	954	920	34	938	18	16	13
322263213	882	868	14				10
211323214	682	664	18				9
004363214	589	571	18				9
014063215	656	638	18				15
004323215	522	505	17				14
114163216	388	364	24				20
442193216	298	276	22				16
332033217	195	162	33	174	12	21	18
311093217	213	180	33	192	12	21	19
TOWNSHIP 33S							
221133304	2634	2630	4				0
004233304	2635	2630	5				0
012353305	2645	2638	7				2
023073306	2598	2590	8				2
322183306	2618	2612	6				0
421363306	2248	2241	7				2
432083308	1956	1946	10				5

KANSAS CODE	NUY CRK TOP	MD CITY BOT	UNIT THICK	UNIT BREAK	UPPER UNIT	LOWER UNIT	HEPLER "C" SS THICK
331213308	2212	2202	10				3
124283308	1990	1981	9				5
131073309	1786	1777	9				3
001143309	1669	1656	13				5
023143309	1730	1720	10				5
114023310	1426	1405	21	1412	7	14	8
214073311	1446	1433	13	1436	3	10	6
111193311	1290	1276	14				5
002143312	900	876	24	886	10	14	12
421253313	736	720	16				9
002013314	582	564	18				13
442353314	604	583	21				15
222063315	676	659	17				15
241113315	438	418	20				17
213193315	494	476	18				14
222033316	195	165	30				10
111113316	224	192	32				14
000193316	420	395	25				20
444233317	428	406	22				16
443293317	86	47	39				18
024323317	67	25	42				20
TOWNSHIP 34S							
422323403	3075	3067	8				0
121143404	2760	2740	20				7
032033405	2572	2554	18				6
013213405	2741	2720	21				12
121273405	2642	2620	22				10
244323407	2432	2424	8				5
133093408	1811	1804	7				2
333103408	1824	1815	9				4
041223409	1572	1559	13				5
222313409	1660	1649	11				5
334133410	1312	1296	16				6
004333410	1446	1430	16				6
441013411	1010	996	14				9
432023411	1031	1016	15				6
113043411	1118	1104	14				6
333063412	1002	990	12				5
141123412	827	812	15				7
241173412	932	917	15				5
211063413	1036	1022	14				9
003083413	779	756	23				6
002073414	646	628	18				6
112193414	698	682	16				8
113353414	662	646	16				11

KANSAS CODE	NUY CRK TOP	MD CITY BOT	UNIT THICK	UNIT BREAK	UPPER UNIT	LOWER UNIT	HEPLER "C" SS THICK
414013415	401	387	14				20
423113415	366	342	24				17
332203415	476	456	20				17
000243415	322	299	23				20
003253415	296	274	22				12
000083416	380	354	26				28
421173416	339	314	25				26
441173417	67	26	41				18
TOWNSHIP 35S							
341043504	2692	2680	12				0
222173507	2374	2367	7				3
412133510	1131	1126	5				2
213033514	630	614	16				10
024123514	672	656	16				11
001033515	416	396	20				18
000043515	479	459	20				16
422083515	472	454	18				16
244103515	419	397	22				19
044123515	331	307	24				19
011083516	272	248	24				20
141183516	288	265	23				19