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Petrographic and Subsurface Analysis of Pennsylvanian

Morrow Sandstones of Southwest Kansas

by

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Thesis directed by Assistant Professor William L. Bilodeau.

The sediments of Morrowan age of southwestern Kansas are commonly referred to as the Morrow Formation. The results of a statistical study indicate that these quartzose sands are primmarily recylced from the craton interior, as further evidenced by the presence of abraded quartz overgrowths on numerous grains. An extensive period of erosion that began during Meramecian time released numerous thin sandstones from the dominantly carbonate strata, especially on the Central Kansas Uplift, and resulted in the deposition of these sands. Volcanic rock fragments and a greater portion of plagioclase are present in sands from two stratigraphic horizons in Morton County. These grains originated from active volcanism in the Ouachita-Marathon orogenic highlands that intermittently produced major eruptions. Extensive diagenetic carbonate cement is present in many samples which may cause misinterpretations of lithologies from well log data.

The Morrow and Chester formations are genetically related, only differing in age, and are difficult to distinguish between in the subsurface, because of their similar lithology, log response and depositional environment. They should be treated as one unit, the Morrow-Chester Formation.

The top of the Morrow and St. Genevieve structure maps have similar trends. Three semi-parallel fault systems are present in Morton County, which may be associated with the north eastern flank of the Keyes Dome, and probably had recurrent movement throughout the Paleozoic. Local thickening on the Morrow-Chester isopach map in central Morton County suggests that portions of the fault systems were active during Morrowan time.

Morrowan rocks were deposited in a warm, humid climate on a slowly subsiding craton. A marine transgression began during Chester time and continued into early Morrow time depositing shallow marine sediments. This was followed by a period of regression. Upper Morrow sandstones were deposited by meandering fluvial systems and fluvial dominated deltaic systems as the epicontinental sea again transgressed the area. Throughout Morrowan time, black shales were deposited under locally anoxic marine conditions. These shales may be important source beds for hydrocarbons.

This abstract is approved as to form and content.

Signed William L. Bilodeau

William L. Bilodeau

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CHAPTER 1

INTRODUCTION

This is a study of the Early Pennsylvanian Morrow Formation in the subsurface of southwestern Kansas. The study area is within the Hugoton Embayment and includes portions or all of Clark, Finney, Grant, Greeley, Hamilton, Haskell, Kearny, Meade, Morton, Scott, Seward, Stanton, Stevens and Wichita counties (Figure 1). Major goals of the study include petrographic and subsurface well log characteristics of the Morrow sandstones, their source area and

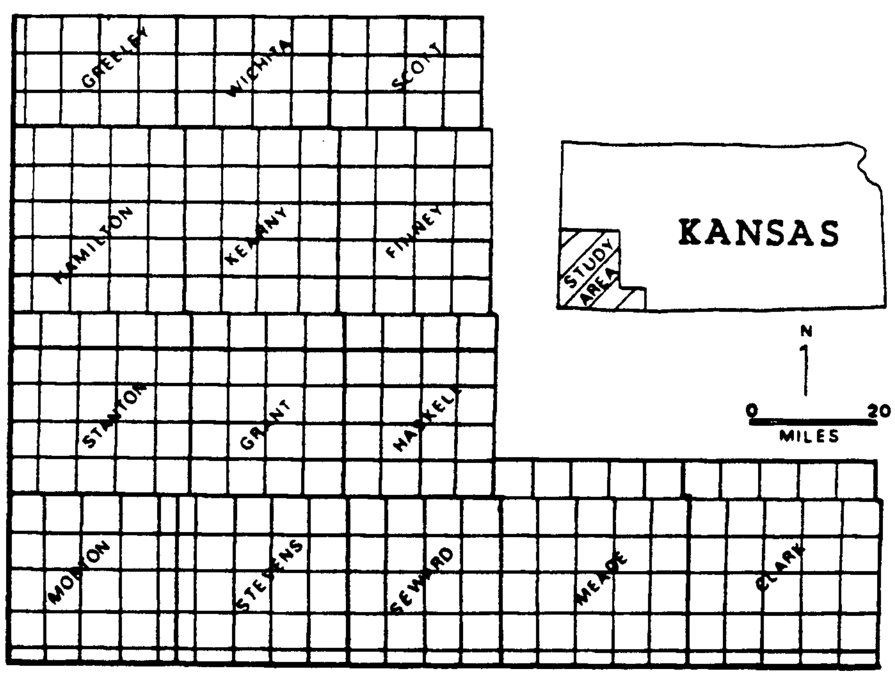

Figure 1 Location of study area.

depositional environments. Regional stratigraphic correlations (well log cross sections) and maps were made to assist in the overall understanding of the Morrow Formation.

Geologic Setting

The Hugoton Embayment is an asymmetrical basin with its axis offset to the west and a shallow shelf to the east. It began forming during Cambro-Ordovician time and was inactive by Mesozoic time (Merriam, 1963). The embayment plunges southward into the Anadarko Basin and is considered to be an extension of the Anadarko. The sediment thickness increases toward both the axis of the Hugoton Embayment and to the south, reaching a maximum total thickness of 9500 ft. (2896 m.). In older literature, the Hugoton Embayment some-times is referred to as the Dodge City Shelf. For the purposes of this paper, the study area is considered to be in the Hugoton Embay-ment. The Dodge City Shelf is considered to be that area to the north and east of the Hugoton Embayment (Figures 2).

During the late Paleozoic, the Hugoton Embayment and the Dodge City Shelf were surrounded by the Keyes Dome to the southwest, the Las Animas Arch to the northwest, the Cambridge Arch to the north and the Central Kansas Uplift to the east. Four sedimentry basins (Salina, Sedwich, Forest City, and Cherokee) and other structures (Nemaha Anticline, Nemaha Ridge and Bourban Arch) were present in the central and eastern portions of the state, but these features had little or no influence on the study area during Morrowan time.

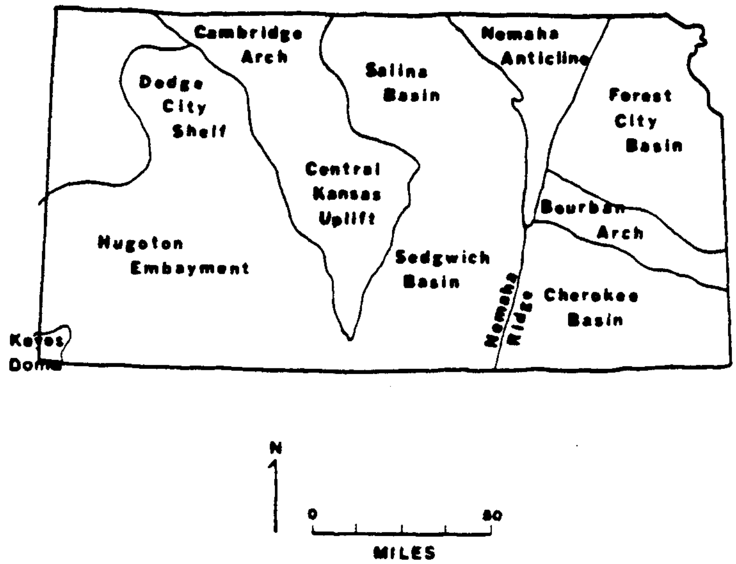

Figure 2 Paleotectonic features of Kansas that have formed in Late Mississippian to Early Pennsylvanian time (modified from Huffman, 1959 and Ebanks et al, 1979).

Earliest Pennsylvanian or Morrowan age sedimentary strata in the Hugoton Embayment are of predominantly clastic origin. They pinch out to the north and east, extend part way into Colorado on the west and thicken to the south. Rocks of this age frequently are called Morrow Formation in Kansas and Colorado and Morrow-Springer Formation in Oklahoma where the section is substantially thicker.

Oil and Gas Production

In the late 1940's and early 1950's, natural gas began to be produced from the Chase Group (Wolfcampian) limestones. The field became known as the Hugoton Gas Field. This field covers most of the study area. These wells are shallow (2000 to 2600 ft. (610 to 793 m.) below the surface), extremely prolific and have long lives.

They are drilled on a 640 acre spacing with the well usually located at the center of each section.

In the early 1960's, natural gas production began from the somewhat deeper (2500 to 3500 ft. (762 to 1067 m.) below the surface) Council Grove horizon, which also are Wolfcampian limestones. These wells are drilled on a 640 acre spacing with the well usually located slightly off center from the Chase well in each section.

Exploration for deeper horizons was minor until the late 1960's. Since that time several deeper hydrocarbon bearing horizons have been discovered (Table 1). Many of these deeper horizons are referred to by their stage or group name. The dominant reservoir rock type is limestone. The Morrow and the Chester are the exception to this with most of their production coming from sandstones.

Table 1 Producing horizons

AGE	NAME USED	PRODUCING HORIZONS
Permian		
Wolfcampian	Chase	Gas
	Council Grove	Gas
Pennsylvanian		
Virgilian	Wabunsee	Gas
Missourian	Lansing-Kansas City	Oil and Gas
Desmoinesian	Marmaton-Cherokee	Oil and Gas
Morrowan	Morrow	Oil and Gas
Mississippian		
Chesterian	Chester	Oil and Gas
Meramecian	St.Genevieve	Oil and Gas
	St. Louis	Oil and Gas

Both oil and gas have been produced from the Morrow in the study area. Most of the traps are stratigraphic, but some are related to structural features (Davis, 1963). Natural gas tends to be the main product in the western portion of the embayment, with both oil and gas produced in the east.

The deepest wells drilled in the area reach depths of approximately 6000 ft. (1829 m.). These well are considered to be relatively shallow and inexpensive to drill. The low drilling cost and the abundance of producing horizons make the Hugoton Embayment an important area for petroleum exploration, although most of the drilling rights to the acreage in the area are held by the Permian limestone production. Recent law suits may force companies who have held this acreage for decades to either drill or give up their lease rights to the deeper horizons.

Purpose

Though oil and gas companies active in the area may have in-house reports that they have kept confidential, no regional studies of the Morrow of southwestern Kansas have been published. This lack of published information has resulted in differences of opinion on the Morrow, in particular the Morrow-Chester boundary. This study provides new information that will promote better communication among those who are interested in the Morrow Formation of the Hugoton Embayment.

The objectives of this study are to:

(1) determine the provenance of the sandstones in the Morrow Formation;

(2) identify the Mississippian-Pennsylvanian Chester-Morrow boundary from well logs by some consistent method;

(3) show regional variations in the structure and thickness of Morrow Formation and associated units;

and

(4) document changes in the depositional environment during Morrowan time.

This is accomplished through analysis of well logs, completion cards, core and thin section samples.

CHAPTER 2

GENERAL STRATIGRAPHY

Though no surface outcrops of Paleozoic rocks are present in the area and few deep wells penetrate below Mississippian strata, most geologic periods are known to be represented by rocks in the Hugoton Embayment (Table 2). Total thickness of the strata range from approximately 7000 ft. (2134 m.) to 9500 ft. (2896 m.) in the study area.

Pre-Mississippian Strata

The oldest sedimentary rocks belong to the Arbuckle Group of Upper Cambrian to Lower Ordovician age and rest unconformably on Precambrian crystalline basement. The Arbuckle is comprised of dolomite in the lower part and dolomite with insoluble chert residue in the upper part (Zeller, 1968).

Upper Ordovician strata of the Simpson Group unconformably overlie the Arbuckle Group. This group contains sandstone, shale and possibly coal. The St. Peter Sandstone, present in much of the central United States, is equivalent to the lower Simpson Group. The Upper Ordovician Viola Limestone overlies the Simpson Group and older strata in the Hugoton Embayment (Zeller, 1968).

Rocks of Silurian and Devonian age are absent in the study area. They are represented by the Hunton Group in northeastern

Table 2 Regional stratigraphy

SYSTEM	STAGE	GROUP	IMPORTANT FORMATIONS
Quaternary (Pleistocene)			Pearlette Ash
Tertiary (Pliocene)			Ogallala
Cretaceous	Upper Lower	Montana Colorado Dakota	
Jurassic		Dockum (?)	Morrison Entrada Equivalent
Permian	Guadalupian Leonardian Wolfcampian	Nipewalla Sumner Chase Council Grove Admire	Stone Corral
Pennsylvanian	Virgilian Missourian Desmoinesian	Wabunsee Shawnee Pedee Lansing Kansas City Marmaton Cherokee	
	Atokan		
	Morrowan		Morrow
Mississippian	Chesterian		Chester
	Meramecian Osagian		St. Genevieve St. Louis Spergen Warsaw
	Kinderhookian		
Ordovician		Simpson	Viola Limestone
Cambro.-Ordovic.		Arbuckle	

Kansas and the deeper portions of the Anadarko Basin in Oklahoma.

Mississippian Strata

The Mississippian period is represented by strata of Kinderhookian, Osagian, Meramecian and Chesterian age. The Mississippian strata unconformably overlie the Viola Limestone in the study area. They attain a maximum thickness of 1700 ft. (518 m.) in the Hugoton Embayment (Zeller, 1968).

The Kinderhookian Stage is comprised of limestone and dolomite with some chert. The Osagian Stage is comprised of limestone and shale that thicken toward the south. A slight angular unconformity may separate Kinderhookian from Osagian strata (Zeller, 1968).

The Meramecian strata lie disconformably upon the Osagian strata, but this is hard to discern in southwestern Kansas. They are comprised of granular, sandy, oolitic and fossiliferous limestone with some dolomite. The formations present in the area appear to lie conformably upon each other. In places, the St. Louis and St. Genevieve formations cannot be differentiated (Zeller, 1968). A major erosional unconformity separates the Meramecian Stage from the overlying strata throughout much of the midcontinent. A karst topography developed on top of the St. Genevieve in eastern Kansas (Goebel and Stewart, 1979) and may have been present in the study area.

The Chesterian Stage is bounded below by an unconformity. The rocks of this age are referred to as the Chester Formation by most of the petroleum industry. The Chester consists of sandstone, shale, and some thin limestone beds. It is present in the southern portion of the study area, but is absent from most of the rest of the state.

Lower Pennsylvanian Morrowan Strata

The Morrow Formation of southwestern Kansas contains those rocks that lie immediately below the Atokan age strata and immediately above Mississippian age rocks. Early workers referred to them as the Kearny Formation after Thompson assigned that name to rocks of Morrowan age (based on several species of Millerella) from a well in Kearny County, Kansas in 1944 (Merriam, 1963). The name Morrow Formation was first applied to rocks located near the town of Morrow in Washington County, Arkansas (Arro, 1965). It is doubtful that the rocks of Morrowan age in southwestern Kansas are genetically related to those in the type locality, but since the petroleum industry and numerous recent authors refer to the Kansas rocks as belonging to the Morrow Formation, this study continues the practice. On well completion cards, numerous petroleum companies refer to a lower Morrowan sandstone as the Keyes Formation. This paper includes the Keyes as part of the Morrow Formation.

Rocks of Morrowan age are found only in the western part of Kansas. Throughout the rest of the state, rocks of this age are missing due to the post St. Genevieve unconformity. The Morrow Formation in western Kansas consists of conglomerate, sandstone, shale, thin limestone and some coal. The formation thickens toward the south, attaining a maximum thickness of approximately 600 ft. (183 m.).

In the Hugoton Embayment and Anadarko Basin, the Morrow commony is subdivided into a lower unit composed of sandstone, shale and thin limestone that was deposited under dominantly marine conditions and an upper unit consisting of sandstone, shale and coal that was deposited in dominantly fluvial and deltaic environments. The position of the stratigraphic horizon that divides the two is very subjective. The Morrow is genetically related to the underlying Chester Formation, differing only in age. It is difficult to distinguish between the Morrow and the Chester in the subsurface. Few paleontology studies have been published in the area. Rock that are considered to be Chester in the study area may actually belong to the Morrow Formation.

Morrow sandstones have been described as having an erratic, discontinuous distribution. They are glauconitic, micaceous, calcareous, argillaceous, feldspathic and/or chert bearing in composition (Abels, 1962). The sandstones and limestones are usually found as discrete packages that are separated from one another by moderately thick shale intervals. Some wells may contain four or five sandstone intervals separated by shale while others may only contain shale (see appendix).

Post Morrowan Strata

Several local unconformities and disconformities are present in the Pennsylvanian strata, with two important ones separating the Morrowan and Atokan stages, and the Atokan and Desmoinesian stages. Carbonate cyclothems are characteristic of the post Morrowan Pennsylvanian strata. They consist of sequences of limestone, shale, thin sandstone and minor coal.

A local unconformity separates Pennsylvanian and Permian strata. The Wolfcampian, Leonardian and Guadalupian stages are represented by carbonate, shale and major salt beds. A major unconformity separates the Permian from the overlying Mesozoic strata.

A group of sandstones and shales, originally considered to be Triassic in age, and now thought to be Jurassic, overlie the Mesozoic strata. They are incorrectly referred to as Dockum (?) and are present in Morton County and the northwesten portion of the study area. Undifferentiated beds of siltstone and sandstone believed to be equivalent to the Entrada Sandstone (Upper Jurassic) also are present in the western portion of the study area, as are Upper Jurassic Morrison shale, sandstone, chert, anhydrite and gypsum beds (Zeller, 1968).

A major unconformity separates Cretaceous strata from the underlying units. In the study area the Cretaceous section is predominantly marine limestone and shale. Both the Comanchean and Gulfian stages (Upper and Lower Cretaceous) are represented. Some Cretaceous rocks are exposed at the surface (Zeller, 1968).

The Cenozoic Era is represented by Pliocene and Pleistocene deposits that unconformably overlie older strata. Of these, the Ogallala (Pliocene), a local aquifer, and the Pearlette Ash (Pleistocene), a time stratigraphic marker, are the most commonly discussed formations.

CHAPTER 3

TECTONIC HISTORY OF THE REGION

There are no published papers giving a complete tectonic overview of the Hugoton Embayment and the surrounding region. This synthesis of papers by numerous authors is presented as a basic outline of the tectonic history of the region. It goes into more detail than is necessary to understand the Morrow sandstones, but is presented in the hope that it will enhance communication and understanding among those interested in the area.

Precambrian

The tectonic history of the southern midcontinent region has been strongly influenced by recurrent movement along Precambrian zones of weakness (Figure 13). The Colorado Lineament is believed to have formed during this time as a composite of numerous unrelated features. The break up of the proto-Pangean megacontinent at about 1.1 to 1.2 billion years ago (Sawkins, 1976) is believed to be associated with the opening of the Central North American (or Keweenewan) Rift (Hinze et al, 1980) and rifting in the Wichita aulacogen (Powell and Phelps, 1977) in Oklahoma. The Wichita aulacogen may have been the result of reactivation of a middle Proterozoic (1.7 to 1.2 b.y.a.) aulacogen. The

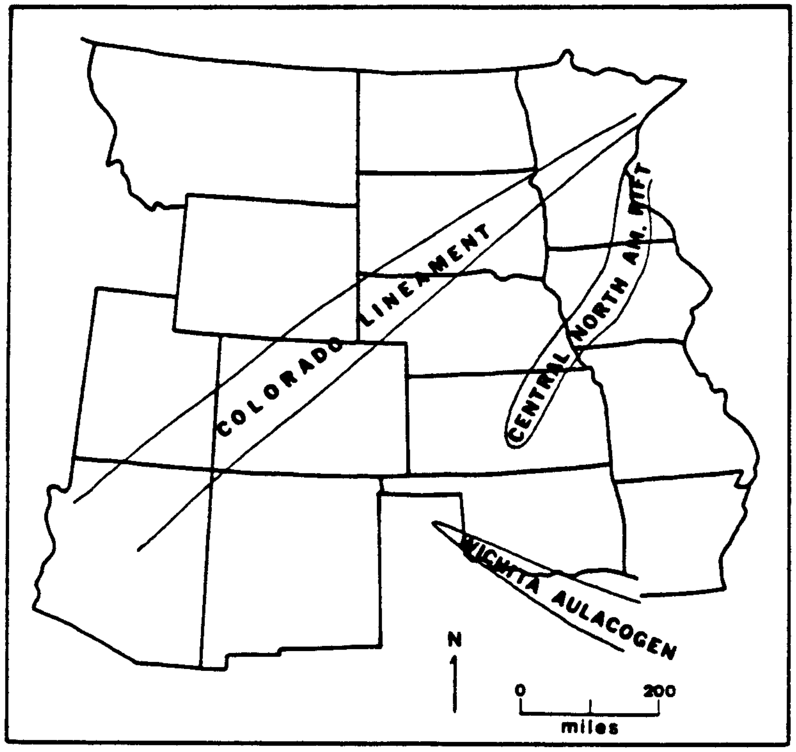

Figure 3 Precambrian features (modified from Brill & Nutti, 1983; Halls, 1978; and Warner, 1978).

The continental collision that produced the Grenville orogeny (1.0 to 0.85 b.y.a.) terminated activity in the Central North American Rift (Muehlberger, 1980). Rifting continued into the Cambrian as the proto-Atlantic (Iapetus) ocean was opening (Hinze) et al, 1980). Most of the midcontinent underwent extensive erosion during this time leaving deeply eroded basement rocks (Ham and Wilson, 1967).

Early Paleozoic

The Late Precambrian rifting produced an Atlantic type continental margin along the southern edge of the midcontinent with the Wichita aulacogen extending into the continent as a failed third arm of an initial triple junction rift (Stewart, J. H., 1976). As the proto-Atlantic ocean grew larger, the continental margin along the midcontinent subsided and became inundated with marine water resulting in the widespread deposition of limestone and dolomite. Carbonate sedimentation continued into the Ordovician.

A few positive areas remained in the midcontinent region throughout Cambrian time. The Transcontinental Arch, a northeast trending feature that probably was related to the Colorado Lineament (Haun, 1980) was inundated in the middle leaving two islands surrounded by an epicontinental sea (Figure 4).

During the Ordovician, the rifted margin along the Atlantic coast became the site of subduction related collisional tectonics. The Taconic orogeny (beginning in the Middle Ordovician) in the Appalachian region probably was the result of

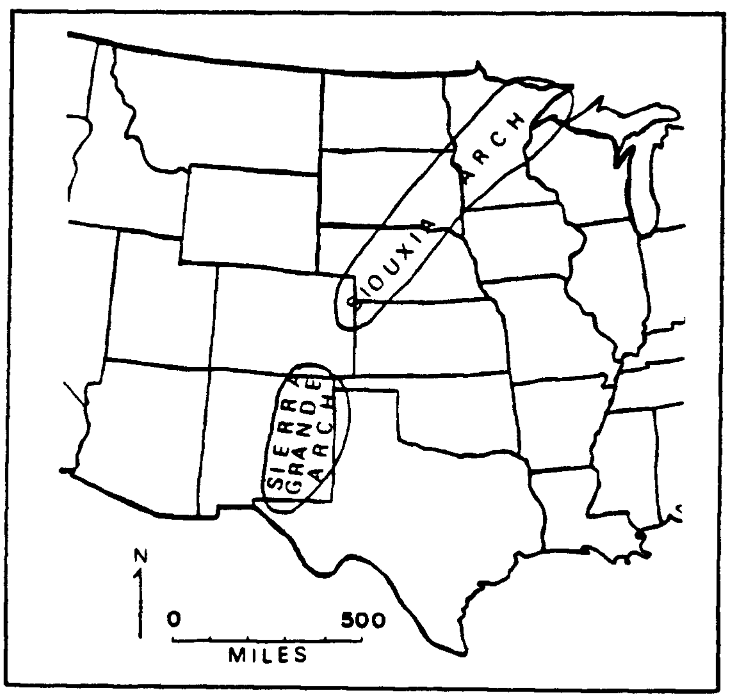

Figure 4 Cambrian Transcontinental Arch (modified from Lockman-Balk, 1971 and Petersen et al, 1980).

the collision between an island arc and the passive margin of the North American craton. This collision set up stresses within the craton that resulted in resurgent tectonics. A large unnamed syncline in central Kansas (Adkinson, 1972) and possibly the Transcontinental Arch underwent vertical movement in the Middle Ordovician, the ancestral Central Kansas Uplift and Cambridge Arch were major features. These structures were associated with a series of northwest trending folds that were present throughout the lowlying area between the Central Kansas Uplift and the site of the Apishapa-Sierra Grande trend to the west (Clair and Volk, 1968).

Numerous unconformities were present within the Ordovician section. A major early Middle Ordovician unconformity was produced by the emergence of the craton and was followed by the deposition of the St. Peter Sandstone in the east (Ham and Wilson, 1967). Sink holes and other features in the Arbuckle may have formed at this time (Adkinson, 1972). These unconformities were the result of broad uplift of the craton or sea level fluctuations related to the Taconic orogeny.

Rocks of Silurian and Devonian age are missing from much of the midcontinent. Shallow marine carbonates probably were deposited over most of the region during this time (Dott and Batten, 1967). Broad uplift of the craton and widespread withdrawal of the epicontinental sea occurred in middle to late Devonian. To the east, the Acadian orogeny of the Appalachians had begun as a result of a continent-continent collision. In the west, the Antler orogeny began in the Late Devonian when an island arc collided with the western margin of North America. Either or both of these events could be related to the emergence of the midcontinent and both should have produced stresses that would cause resurgent tectonics in the midcontinent. Throughout this time, subduction was continuing offshore, south of the Ouachita Trough and the southern passive margin of North America (Morris, 1974).

Many arches and basins were distributed throughout the southern midcontinent region during the Devonian (Figure 5). The Transcontinental Arch was a high that extended from Nebraska into Colorado during the Late Devonian. The Chautaqua Arch and ancestral Central Kansas Uplift (also called Ellis Arch) separated the North Kansas basin from the South West Kansas basin (Craig and Varnes, 1979). The ancestral Central Kansas Uplift was an extension of the Transcontinental Arch.

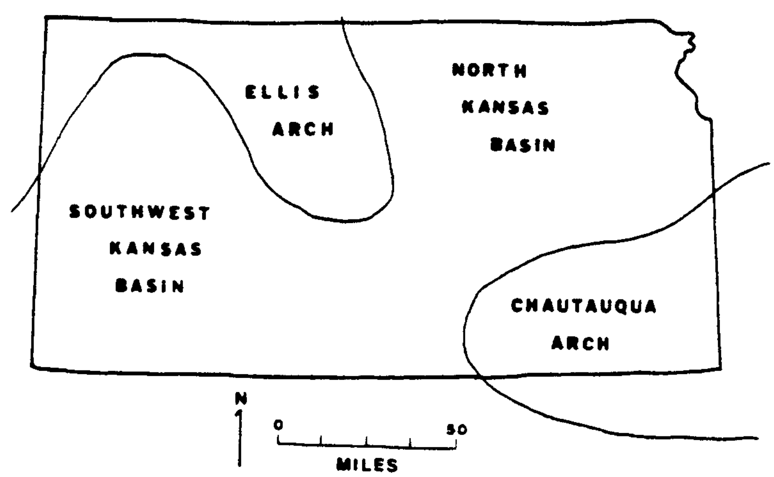

Figure 5 Pre-Mississippian structures (modified from Goebel and Stewart, 1979).

Mississippian

Tectonic activity was at a minimum at the beginning of the Mississippian Period. The transgression that had deposited black shales over much of eastern Kansas and Oklahoma expanded into western Kansas during Kinderhookian time resulting in carbonate deposition. As North America became progressively closer to Pangea, tectonic activity in the midcontinent region increased (Craig and Varnes, 1979). The Transcontinental Arch which had been uplifted in the Devonian, remained a positive area with intermittent submergence throughout the Mississippian Period. The Transcontinental Arch and its probable southern extension the Texas Arch (Figure 6) acted as an axis that separated the western and eastern seas (Lane and DeKeyser, 1980). Minor positive movement in the ancestral Central Kansas Uplift may have taken place during the Kinderhookian stage (Craig and Varnes, 1979). A north-south trending land mass coincident with the present Front Range and Wet Mountains in Colorado underwent recurrent positive movement exposing some Precambrian rocks at this time (DeVoto, 1980a).

During the Osagian stage, rapid subsidence began in the Ouachita Trough, Anadarko Basin and Hugoton Embayment. The Ouachita Trough was composed of a remnant ocean basin, trench and accretionary prism of the approaching arc complex that was eventually thrust up on the passive margin (Lillie et al, 1983). North American had begun to collide with Pangea in the Appalachian region. The closing of the marginal sea separating the two continents would continue in a scissor fashion through the Pennsylvanian Period (Graham et al, 1975). The Sierra Grande Uplift was positive and

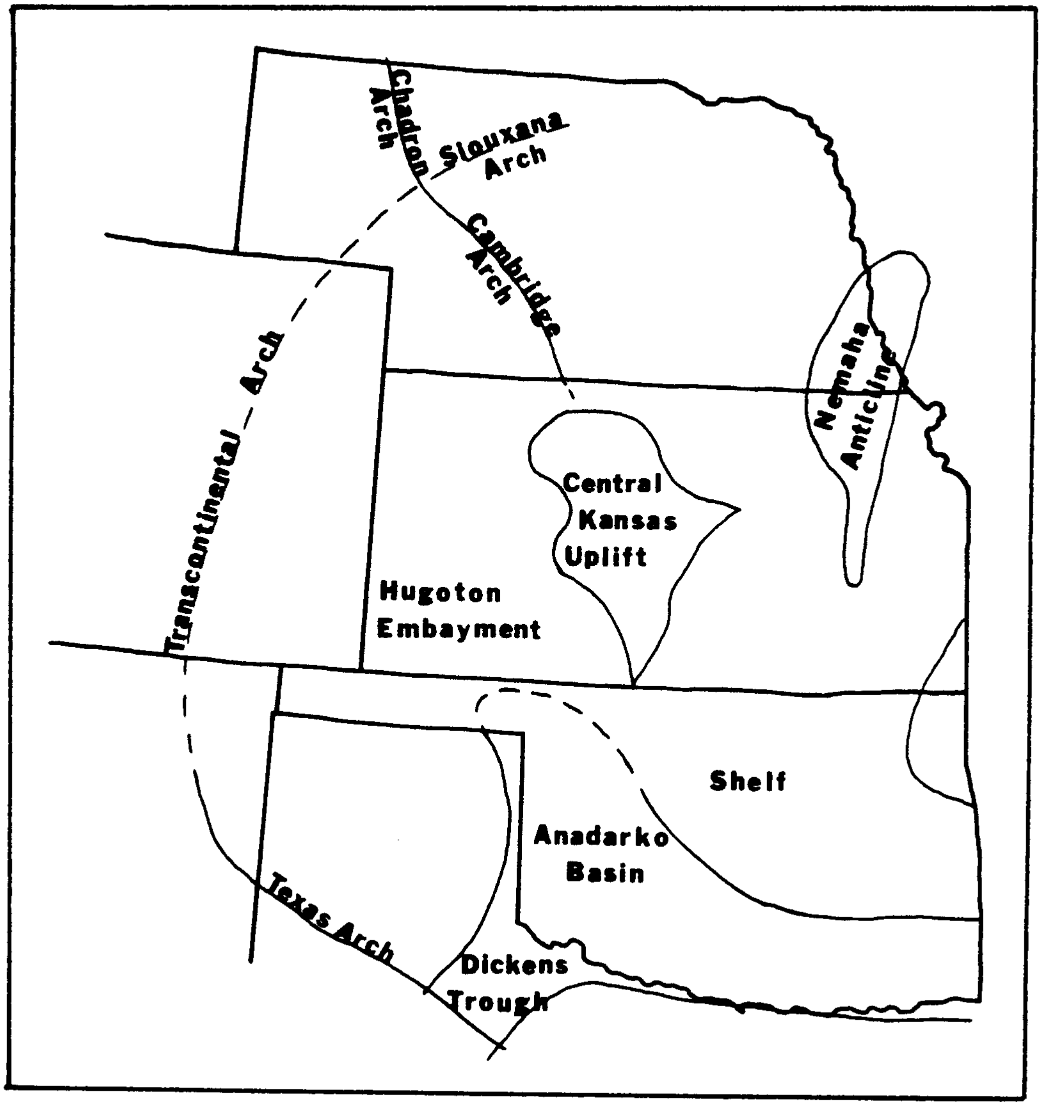

Figure 6 Mississippian structures (modified from Craig & Varnes, 1979 and Frezon & Jordan, 1979).

tectonically active at this time (DeVoto, 1980a).

Minor regressions of the epicontinental sea from the shelf area during the Meramecian stage resulted in the deposition of intraformational conglomerates within the St. Louis carbonate sequence over much of Kansas (Craig and Varnes, 1979). Positive movement of the ancient Siouxia Axis of the Transcontinental Arch (Clair and Volk, 1968) may have caused this minor regression and probably was the source of clastics. Locally, anhydrite was deposited within the St. Louis (Goebel, 1968) as a result of restricted marine conditions in a warm shallow sea. Erosion of the uplifted areas in Colorado exposed Precambrian rocks. Meramecian tectonism occurred within the vicinity of the Sierra Grande Uplift (DeVoto, 1980a).

By the late Mississippian, the midcontinent was no longer tectonically quiet. Volcanic debris began to accumulate in the Ouachita Trough during Meramecian time and continued to accumulate through the Chester (Glink, 1979). The passive continental margin of southern North America was drawn southward into the trough during late Mississippian (Meremecian) time (Lillie et al, 1983) resulting in uplift of the overriding subduction complex (Ouachita Trough) and accumulation of sediment in the subsiding foreland basin (Walper, 1977). Positive movement of the Central Kansas Uplift (Goebels and Stewart, 1979) the Nemaha Anticline along the Central North American Rift (Brown et al, 1982) and the Chadron and Cambridge Arches (Anderman and Ackman, 1963) began at this time. The Wichita Mountains also began to rise as a chain of transpressional horsts on the south side of the present Anadarko Basin along the

Precambrian fault system (King, 1975). Tweto (1980) and DeVoto (1980a) gave evidence of positive movement of the Sierra Grande Uplift of the Ancestral Rocky Mountains and erosion of its Precambrian core during Meramecian and Chesterian time along with positive relief on other Ancestral Rocky Mountain areas.

As the craton was uplifted at the end of the Meramecian stage, the seas withdrew from the midcontinent shelf areas. The shelf underwent extensive erosion (Frezon and Dixon, 1979) with previously deposited rocks stripped away from many areas. A humid climate was accompanied by extensive karst development of the Mississippian carbonates in much of the midcontinent. The solution erosion removed Mississippian carbonates from uplifted areas in Colorado exposing Precambrian rocks (DeVoto, 1980a).

The Anadarko Basin continued to subside during this time. During the Chester stage, the Hugoton Embayment also began to subside with clastic sedimentation becoming dominant (Craig and Varnes, 1979). Fluvial, deltaic and marginal marine processes became important in these areas. These conditions continued into the Pennsylvanian.

Early Pennsylvanian Morrowan

While erosion of the craton continued over much of the midcontinent (as the sea reached its maximum regression (Moore, 1979), a mildly downwarped belt west of the slightly positive Siouxia landmass extended from Canada to the Anadarko Basin within which clastic sediments were being deposited by fluvial and deltaic systems (Figure 7). The Hugoton Embayment was part of this

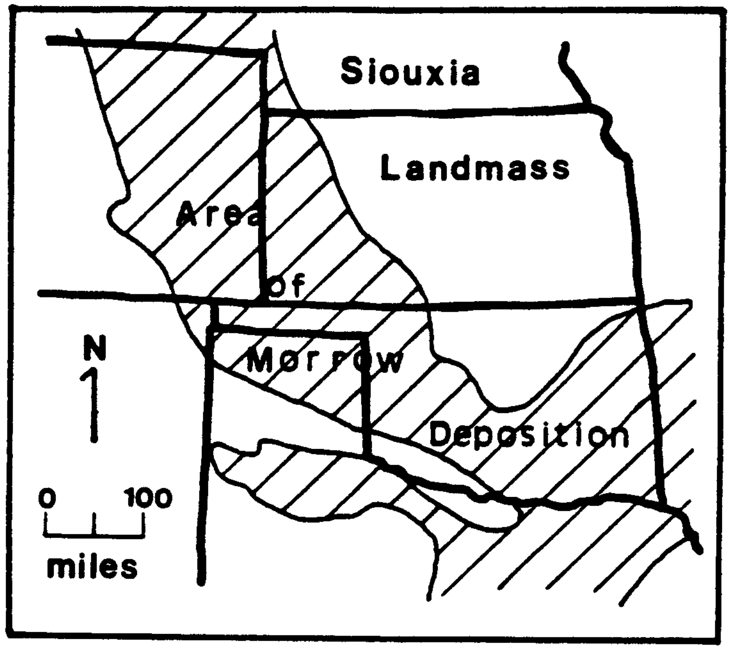

Figure 7 Area of deposition during Morrow time (modified from Moore, 1979).

downwarped area (Stewart, G.F., 1975). The Siouxia landmass included the Central Kansas Uplift, Cambridge Arch and Nemaha Ridge (McKee, 1975). The Anadarko Basin began to subside rapidly receiving a thick layer of fine clastics at this time (Moore, 1979).

The Amarillo-Wichita-Criner Hills uplift began to be raised at this time along high angle faults (McKee, 1975) which continued to be active through most of the Pennsylvanian (Freezon and Dixon, 1975). The uplift occurred along what had previously been the axis of the Anadarko Basin changing the basin's geometry from symmetrical, characteristic or an aulacogen, to asymmetrical, commonly found in foreland basins.

DeVoto (1980a) gave stratigraphic and sedimentalogical evidence for uplift and erosion of Precambrian rocks in the ancestral Front Range, ancestral Uncompahgre and Apishapa uplifts during Morrowan time. Precambrian rocks also were exposed on the Transcontinental Arch in northeast Colorado. DeVoto states that the ancestral Front Range and Apishapa uplifts (Ancestral Rocky Mountains) created relief and erosional land areas that shed terrigenous detritus into depositional basins to the east during this time.

Post Morrowan

North America and Pangea collided in the Ouachita region during Atokan time. The deformation that resulted from the collision is referred to as the Ouachita orogeny. It produced wrench faulting along the Amarillo-Wichita-Criner Hills causing uplift and thrust faulting (Burgess, 1976). North and northwest compressive stresses became active causing a chain of foredeep basins and arches. Kluth and Coney (1981) hypothesize that this northwestward spread of deformation caused the uplift of the Ancestral Rockies at this time. They state that the stresses began to affect the area by the Atokan, first forming the Apishapa and Uncompahgre uplifts. During this time the Anadarko Basin and Hugoton Embayment continued to subside. The sea transgressed the area and carbonate deposition began.

The Amarillo-Wichita-Criner Hills (McKee, 1975) and the Uncompahgre, Frontrange and Apishapa uplifts of the Ancestral Rocky Mountains (Kluth and Coney, 1981) reached their maximum elevations during the Desmoinesian stage while carbonate deposition continued in the Hugoton Embayment and Anadarko Basin. By Missiourian time and on through Virgilian time, most of the rest of the southern midcontinent platform area was covered by a shallow sea. Subsidence in the Hugoton Embayment slowed until the basin was no longer a recognizable structure at the end of Missourian time (McKee, 1975).

During the Permian a new basin, the Central Kansas Basin, began to subside intermittently. It included the area that had formerly been the Central Kansas Uplift (Mudge, 1967). The central midcontinent was a site of cyclic carbonate deposition and three major periods of evaporite deposition during the Permian. The Anadarko Basin underwent its final stage of filling at this time.

An extended period of erosion occurred from the end of the Permian into late Triassic or Jurassic over the midcontinent. Jurassic sandstones were the first sediments deposited after this period of erosion. The Cretaceous epicontinental sea covered much of the area depositing a blanket of shallow marine sediments. The Laramide orogeny (Late Cretaceous to Paleocene) was responsible for the uplift of the Las Animas Arch in Colorado to its present configuration (Clark and Volk, 1968) and probably affected the study area to a minor degree.

CHAPTER 4

PETROGRAPHIC STUDY

Introduction

Provenance of a sandstone is important in controlling the framework composition and may affect grain size, sorting and susceptibility to diagenesis. Although it is frequently ignored, knowing the source area may be extremely useful in predicting depositional trends and the location of good reservoirs. Information on the provenance of Morrow sandstones in southwestern Kansas is hard to find and is often based on ideas that have not been backed by factual information. This portion of the study uses modal analysis data from thin sections and regional paleogeographic and tectonic information to identify possible source areas of the Morrow sandstones in southwestern Kansas.

Method of Study

Fifty-one thin sections from 19 wells were examined in this study (Table 3). Twenty-eight of the thin sections were borrowed from the Kansas Geological Survey (KGS). They represent 7 wells. Cores were examined from 6 of these wells. These sections were not stained for feldspar or carbonate and were not blue dye impregnated. Many of them are of irregular thickness and have plucked and cracked grains. Nineteen of the KGS sections

Table 3 Thin section samples

LOCATION	WELL NAME	SAMPLE DEPTH
5 T18S R41W	Terrel Wheeler # 1(TW)	5184, 5214
36 T19S R35W	Lauch Lehman # 1 (LL)	4868,4906
5 T21S R38W	Cleary Rupp # 2 (CR)	5025
27 T24S R33W	Cities Service Tait C # 4 (CT)	4776,4783
4 T29S R42W	Superior Tucker 68# A 4 (ST)	5380
36 T30S R35W	Anadarko McClelland B # 3 (AM)	5656.5,5667
1 T31S R35W	Mobil Cutter # 1 (MC)	5323
6 T33S R29W	Imperial Bolan # 1 (IB)	5725.3, 5735.5,5742, 5749.2,5754.3,5758.3 *
19 T33S R37W	Anadarko Nell A #1 (NA)	6051,6071.5
10 T33S R38W	Anadarko Gaskill A # 2 (GA)	6010.9, 6029.9 *
6 T33S R40W	Anadarko Low G #11 (LG)	5370,5372.7, 5373.5, 5376 *
8 T33S R40W	Anadarko Low A # 5 (LA)	5615.8, 5641 *
9 T33S R41W	Anadarko Jones B # 1 (AJ)	5048,5052,5057
19 T33S R42W	Cities Service Williams D # 1 (WD)	4482, 4484, 4485.3, 4486.3, 4490.3, 4491.9, 4493.8, 4495.3, 4505 *
16 T34S R33W	Lario Pennington (LP)	5933,5937,5940,5945, 5949 *
5 T35S R41W	Cities Service WMS 3-205W (C)	5128,5143.7
5 T35S R41W	Cities Service WMS 3-206W (C-)	5102,5120
13 T35S R41W	Cities Service Kniffen A #2 (CK)	6247.4
11 T35S R42W	Cities Service Horton C-3 (CH)	4684,4692

* Samples borrowed from the Kansas Geological Survey

were examined by point count. Twenty-three thin sections were made from core samples from Kansas Geological Survey core. They represent 13 wells. These thin sections were made by using the blue dye impregnation method and were stained for potassium feldspar and calcite. Seventeen of them were examined by point count.

Before a modal analysis was undertaken, a determination was made as to what data was needed since a point count made for provenance information uses different parameters than one done for diagenetic purposes. This study followed the format used by Dickinson and Suczek (1979) to determine provenance of sandstones. Table 4 is a sample of the point count tally sheet used for all point counts made in this study. The numerous subdivisions on the form permit the collecting of as much information as possible from a single point count. As many as 30 categories may have been used on a particular sample in this study. Many of these categories were not of value to this provenance study, but the raw data is available for other studies, if needed. The tally information was transferred to a Sandstone Point Count Data sheet (Table 5) and was statistically manipulated into the parameters outlined by Dickinson and Suczek (1979). This data sheet also provides information on grain size, sorting, etc. for each sample.

Each of the 51 thin sections was examined initially to identify grain size, sorting and note a brief description. It was then determined whether or not the section was suitable for modal analysis by point count based on lithology and thin section quality. Grain size information for each section was used to set the point count distance between grains to a spacing that was

Table 4 Point count tally sheet

thin section ____________

location ____________

Qm undulose	
Qm straight	Qm
Qp chert	Qp
F plagioclase	P
F potassium	K
L volcanic	L
L metavolc.	
L mica	Lv
L plutonic	Ls
L comp. qtz. crenulated	
L comp. qtz. straight	
L metasedimentary	
L shale	
L sandstone	
L siltstone	
L carbonate	
L coal	
L ferro mag.	
L	
L	
Au	
Au	Au
Au	
Au	
Au	
Au	
Au	
Au	
M	
M	M
ø intergranular	
ø intragranular	ø
ø oversized pore	
Ac	Ac
Ac	
Ac	
Ac	

Table 5 Point count data sheet

(after Dickinson and Suczek, 1979)

thin section ______________________
location ______________________
____

porosity: visual ________ measured ________
permeability ______________________

sample type ______________________

	raw value	total %	QFL %
Q STABLE QUARTZOSE GRAINS	(____)	(____)	(____)
Qm monocrystalline	____	____	____
Qp polycrystalline (chert)	____	____	____
F MONOCRYSTALLINE FELDSPARS	(____)	(____)	(____)
P plagioclase	____	____	____
K potassium	____	____	____
L UNSTABLE POLYCRYSTALLINE LITHICS	(____)	(____)	(____)
Lv volcanic & metavolcanic	____	____	____
Ls sedimentary & metasediments	____	____	____
QFL POINTS COUNTED	(____)	(____)	
AUTHIGENIC MINERALS	(____)	(____)	Lt = L + Qp = ____
____	____	____	
____	____	____	
____	____	____	Qm ____ F ____ Lt ____
____	____	____	
____	____	____	
____	____	____	
____	____	____	
____	____	____	Qp ____ Lv ____ Ls ____
MATRIX MATERIAL	____	____	
POROSITY	(____)	(____)	
intergranular	____	____	
intragranular	____	____	Qm ____ P ____ K ____
oversized pores	____	____	
ACCESSORIES	____	____	
OTHERS (drilling mud, unknowns, etc.)	____	____	
TOTAL POINTS COUNTED	____	____	

Mean grain size (mm) ______ Maximum size (mm) ______ Sorting ______
Contacts ______________________
Packing ______________________
Allignment ______________________
Rounding-Sphericity ______________________
Comments and significant features ______________________
____
____

Lithologic Name ______________________

SUMMARY DESCRIPTION ______________________
____

greater than the largest grain in that section. The sections were counted in a grid pattern over as much of the rock sample as possible. From industry experience as a sandstone petrographer it was concluded that after a minimum of 200 counts, additional data points do not significantly change the statistics. The main components of interest to this study are quartz (Q), feldspar (F) and lithic (L) fraction; therefore, the operator tried to count at least 200 QLF points per thin section. The numerous additional categories resulted in the total point counts made per section numbering as high as 541 data points. Due to very coarse grain size, extensive cement or matrix, or small rock sample, five thin sections of the 37 counted had less than 200 QFL data points.

Dickinson-Suczek Provenance Study

Many authors have suggested criteria that can be used to determine provenance from thin section analysis. The Dickinson-Suczek procedure was selected because it provides a method by which sediments from numerous plate tectonic settings, including both uplifted basement and craton interior of a cratonic block, can be differentiated. They use four triangular diagrams based on framework grain information to identify the different provenance types. The diagrams are the QFL, QmFLt, QpLvLs, and QmPK (Figure 8).

On the QFL diagram, the Q represents all monocrystalline quartz (Qm) grains and polycrystalline chert (Qp); the F represents

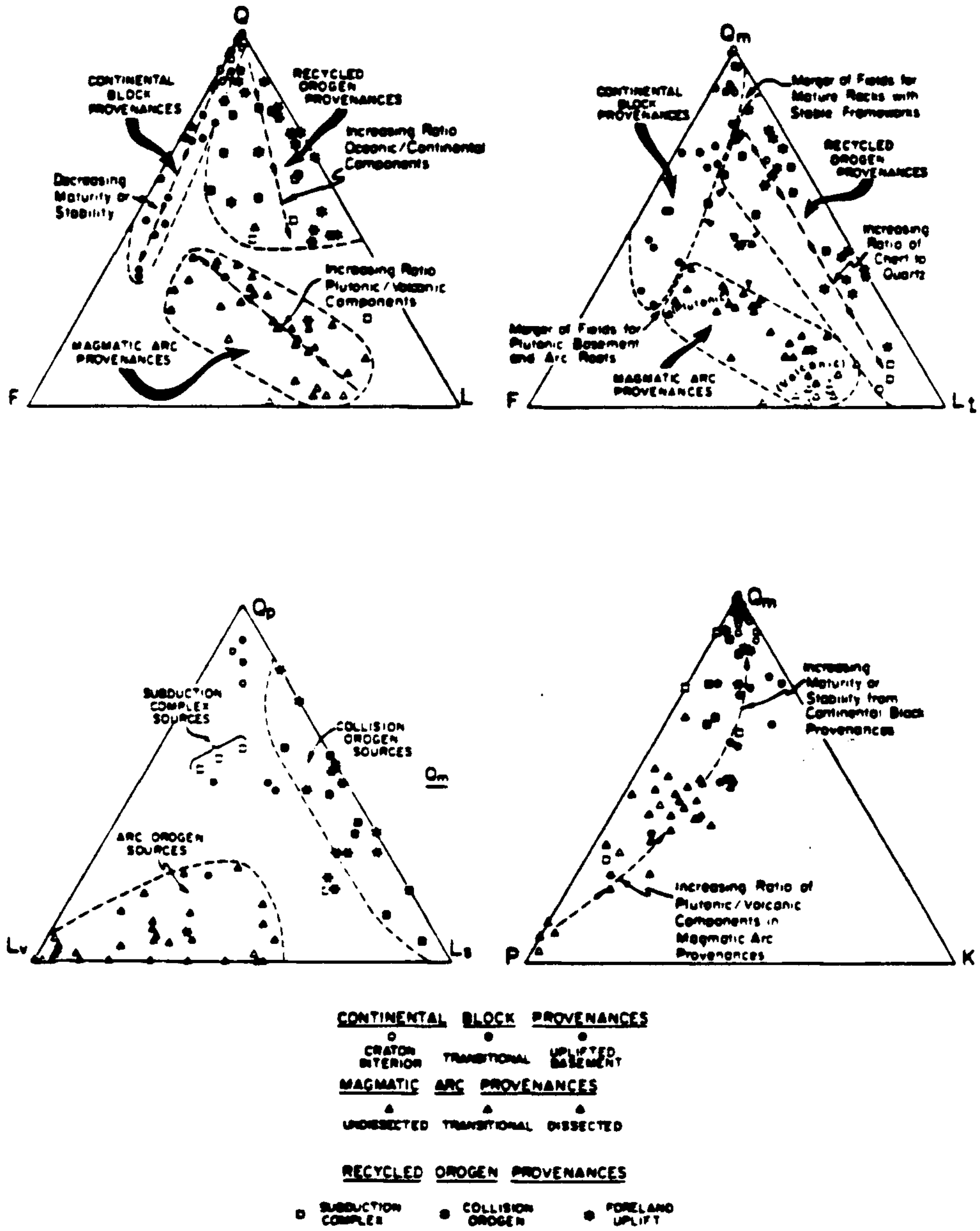

Figure 8 Triangular diagrams used to determine the provenance of sandstones based on framework grain composition (from Dickinson and Suczek, 1979).

all monocrystalline plagioclase (P) and potassium (K) feldspar; and the L represents all polycrystalline lithic fragments except carbonate fragments and glauconite which are ignored. Location of points on this diagram can be subdivided into three main provenances: continental block, magmatic arc and recycled orogen. Each of these provenances is further subdivided into three more specific provenance types. This type of QFL diagram is very useful in determining the provenance of the Morrow sandstones.

The end members of the QmFLt diagram are comprised of monocrystalline quartz (Qm), total feldspar (F), and total lithic (L) plus chert (Qp) which is denoted as Lt. Again the three main provenance types occupy certain areas of the diagram and can be further subdivided into more specific provenance types. This diagram also is important in determining the provenance of Morrow sandstone.

The QpLvLs diagram displays data on the different proportions of lithic fragments. Total chert is represented by Qp, total volcanic and metavolcanic by Lv and total unstable sedimentary and metasedimentary (excluding carbonates) by Ls. This diagram is best used to differentiate between recycled orogen and magmatic arc provenances and is, therefore, of limited value in studying Morrow sandstones of southwestern Kansas.

The QmPK plot represents the monocrystalline quartz (Qm), plagioclases (P) and potassium (K) feldspar grains. It is used to differentiate between undissected and dissected magmatic arcs and changes in the maturity or stability of the continental block provenance.

Results

The sandstones examined in this study are quartz rich sandstones with minor to moderate amounts of feldspar and rock fragments. Monocrystalline quartz with undulose extinction is the predominant variety of the quartzose grains. Quartzose grains include monocrystalline grains with undulose extinction (Qmu) or straight extinction (Qms), composite quartz grains (which are tallied as lithics) with straight internal grain boundaries (Qsc) or crenulated internal grain boundaries (Qcc), and chert (Qp) (Figure 9). Chert is present in 37 samples. The pie diagrams in Figure 10 show the relative proportions of potassium (K) and plagioclase (P) feldspar, plutonic rock fragments (PRF), sedimentary rock fragments (SRF), metamorphic rock fragments (MRF) and volcanic rock fragments (VRF). Potassium feldspar is the most abundant feldspar in 30 of the samples. Seven samples representing four wells, contain volcanic rock fragments and have higher levels of plagioclase than the other samples. Glauconite, carbonate rock fragments and marine fossils are present in many of the samples, but since they probably were introduced by the depositional environment, they were not used in provenance calculations.

The framework grain information from the 37 samples studied was tabulated (Table 6) and plotted on four triangular diagrams (Figure 11). The QFL diagram shows that the samples plotted into two fields. Many of the samples clearly fall in the craton interior provenance, indicating that the sands were derived from exposed shield areas

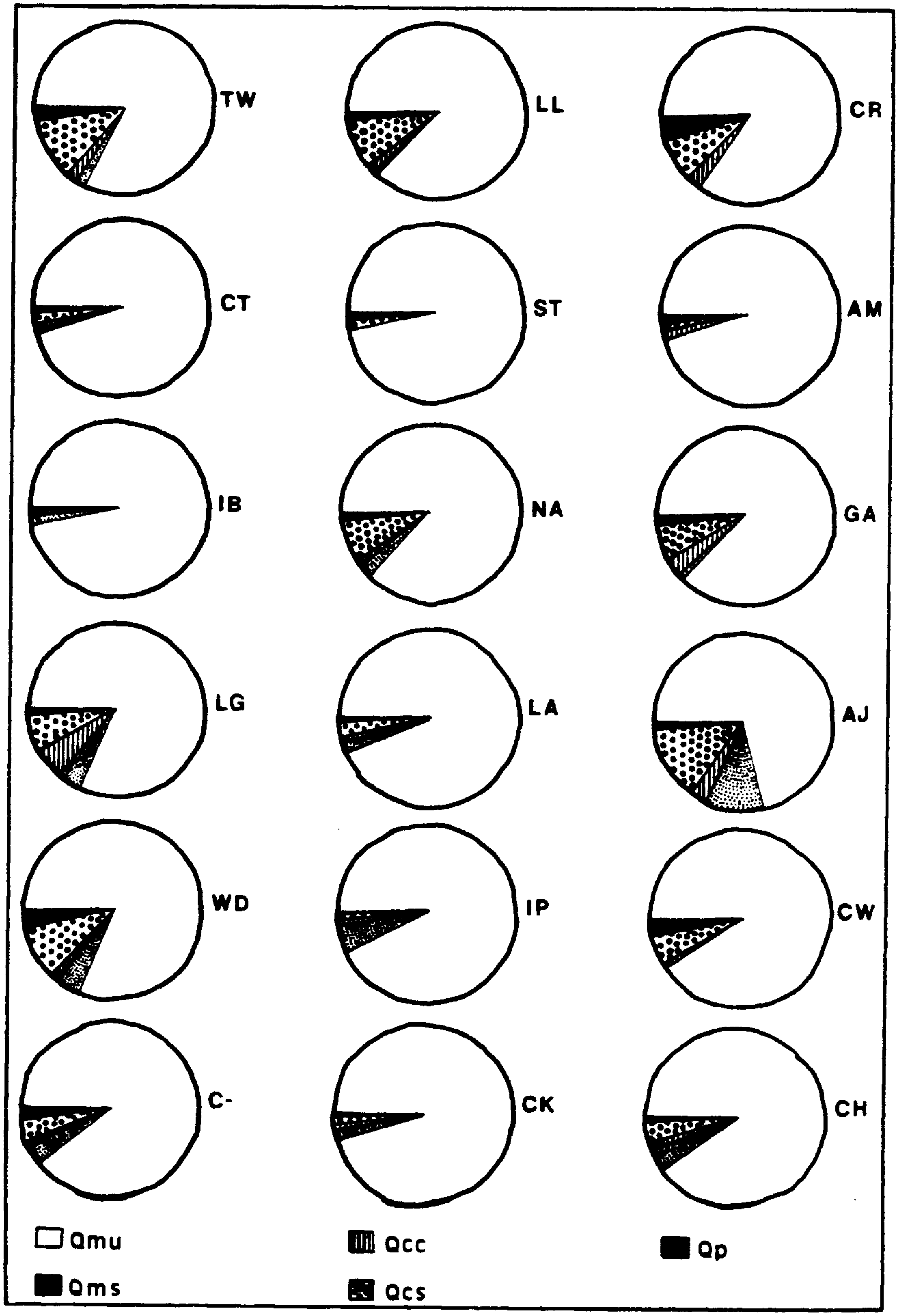

Figure 9 Relative percentages of quartzose grains

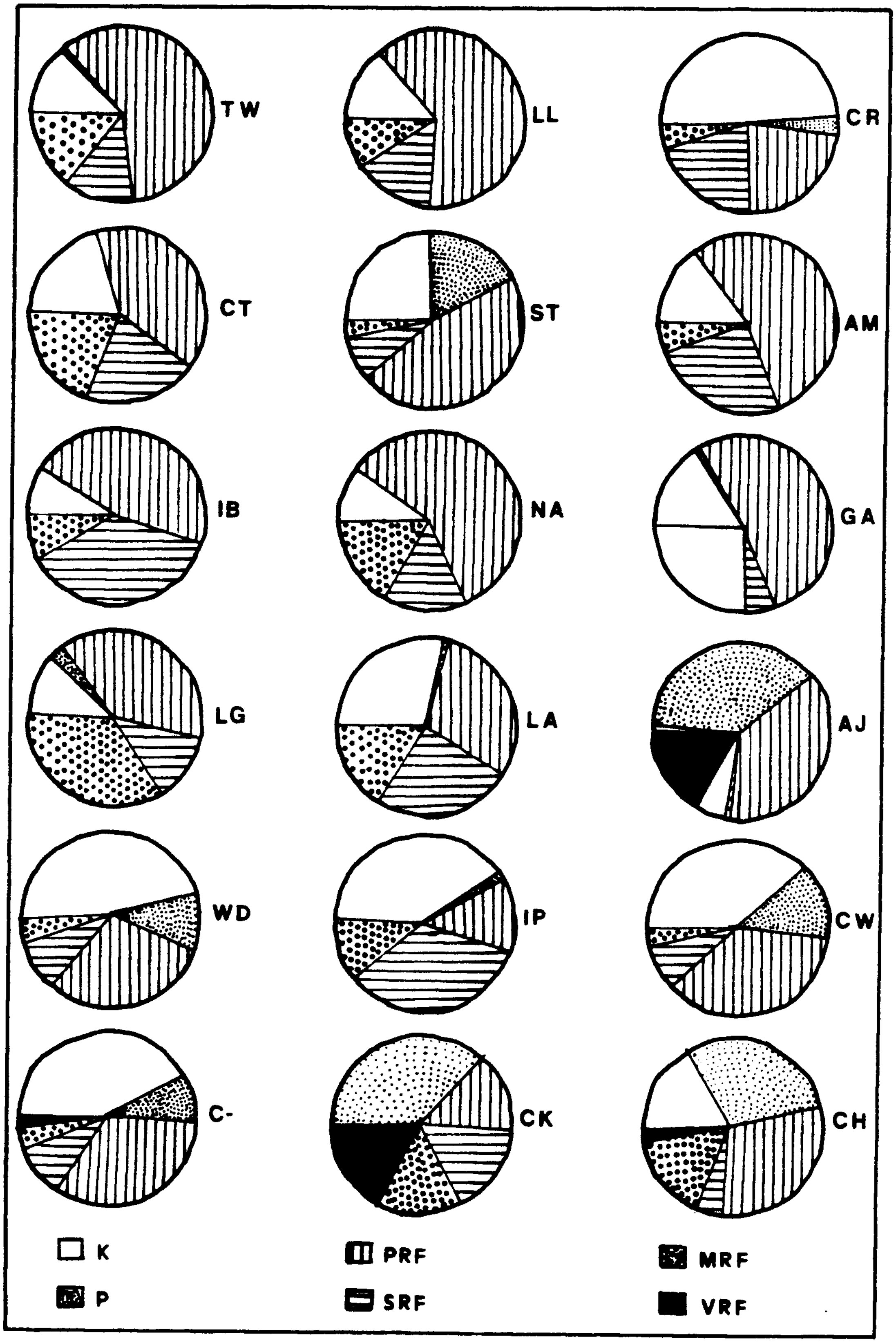

Figure 10 Relative percentages of feldspar and lithics

Table 6 Framework grain data

SAMPLE	QFL COUNTS	Q F L	Qm F Lt	Qp Lv Ls	Qm P K	Q	F	L	Qm	Qp	P	K	Lv	Ls	Lt
TW 5184	341	77/2/21	76/2/22	4/92/4	97/0/3	261	7	73	258	3	0	7	70	3	76
TW 5214	211	89/4/7	84/4/12	38/25/32	95/1/4	198	8	16	188	10	1	7	7	9	26
LL 4868	333	82/2/14	81/2/17	13/11/76	97/0/3	278	7	48	271	7	0	7	6	42	55
LL 4906	146	92/2/6				134	3	9	134	0	0	3	1	8	9
CR 5025	202	79/13/12	75/13/12	36/24/40	85/1/14	160	26	16	151	9	2	24	6	10	25
CT 4776	305	95/1/4	94/1/5	25/25/50	99/0/1	289	4	12	285	4	0	4	4	8	16
ST 5380	363	94/3/3	93/3/4	14/29/57	97/1/2	341	10	12	339	2	4	6	4	8	14
AM 5667	208	96/1/3	94/1/5	29/29/42	99/0/1	278	2	10	274	4	0	2	4	6	14
IB 5735	318	96/2/2	95/2/3	27/0/73	98/0/2	304	6	8	301	3	0	6	0	8	11
IB 5754	142	97/2/1				138	3	1	137	1	0	3	0	1	2
IB 5758	264	99/0/1	99/0/1	50/0/50	99/0/1	262	1	1	261	1	0	1	0	1	2
NA 6051	261	88/2/10	87/3/10	7/0/93	97/0/3	230	6	25	228	2	0	6	0	25	27
NA 6071	276	89/1/10	89/1/10	7/0/93	99/0/1	247	1	28	245	2	0	1	0	28	30
GA 6010	185	88/5/7	87/5/8	13/0/87	95/0/5	163	9	13	161	2	0	9	0	13	15
GA 6029	317	83/1/16	83/1/16	2/0/98	98/1/1	263	4	50	262	1	1	3	-	50	51
LG 5370	302	80/2/18	80/2/18	2/56/42	97/1/2	241	7	54	240	1	2	5	31	23	55
LG 5372	288	83/2/15	83/2/15	0/27/73	97/1/2	238	6	44	238	0	1	5	12	32	44
LG 5353	261	89/3/8	89/3/8	0/57/43	96/1/3	231	9	21	231	0	3	6	12	9	21
LG 5376	307	90/2/8	88/2/10	18/41/41	98/0/2	276	5	26	270	6	0	5	13	13	32
LA 5615	298	88/5/7	87/5/8	17/33/50	94/1/5	263	15	20	259	4	1	14	8	12	24
LA 5641	318	89/2/9	88/3/9	7/20/73	97/0/3	282	8	28	280	2	0	8	6	22	30
AJ 5048	393	57/15/28	56/15/28	4/62/34	78/21/1	223	60	110	219	4	59	1	71	39	114
AJ 5052	319	52/24/24	52/24/24	0/56/44	69/17/14	167	77	75	167	0	77	0	42	33	75
WD 4484	288	75/15/10	72/16/12	18/21/61	83/4/13	215	45	28	209	6	11	34	7	21	34
WD 4491	264	74/14/11	72/14/14	19/19/62	83/2/15	196	38	30	189	7	4	34	7	23	37
WD 4482	53	85/6/9				45	3	5	39	6	1	2	1	4	11
IP 5933	245	95/4/1	95/4/1	50/0/50	96/0/4	234	10	1	233	1	1	9	0	1	2
IP 5937	255	95/2/3	95/2/3	22/44/34	98/0/2	243	5	7	241	2	0	5	4	3	9
IP 5940	238	95/2/3	95/2/3	25/25/50	98/0/2	227	5	6	225	2	0	5	2	4	8
IP 5945	256	93/5/2	92/5/3	38/38/24	95/0/5	239	12	5	236	3	0	12	3	2	8
CW 5128	390	84/10/6	83/10/7	22/32/46	89/4/7	329	39	22	323	6	15	24	9	13	28
CW 5143	347	80/9/11	78/9/13	11/34/55	89/1/10	276	32	39	271	5	4	28	15	24	44
C- 5102	331	79/11/10	77/11/12	16/34/51	87/3/10	261	38	32	255	6	8	30	13	19	38
C- 5120	356	79/13/8	76/13/11	24/42/34	85/3/12	280	47	29	271	9	8	39	16	13	38
CK 6247	327	83/7/10	82/7/11	8/62/30	92/8/0	271	22	34	268	3	22	0	23	11	37
CH 4684	301	86/9/5	84/9/7	20/30/50	90/6/4	257	28	16	253	4	17	11	6	10	20
CH 4692	139	78/9/13	77/9/14	86/6/8	89/7/4	270	32	46	269	1	21	11	20	26	47

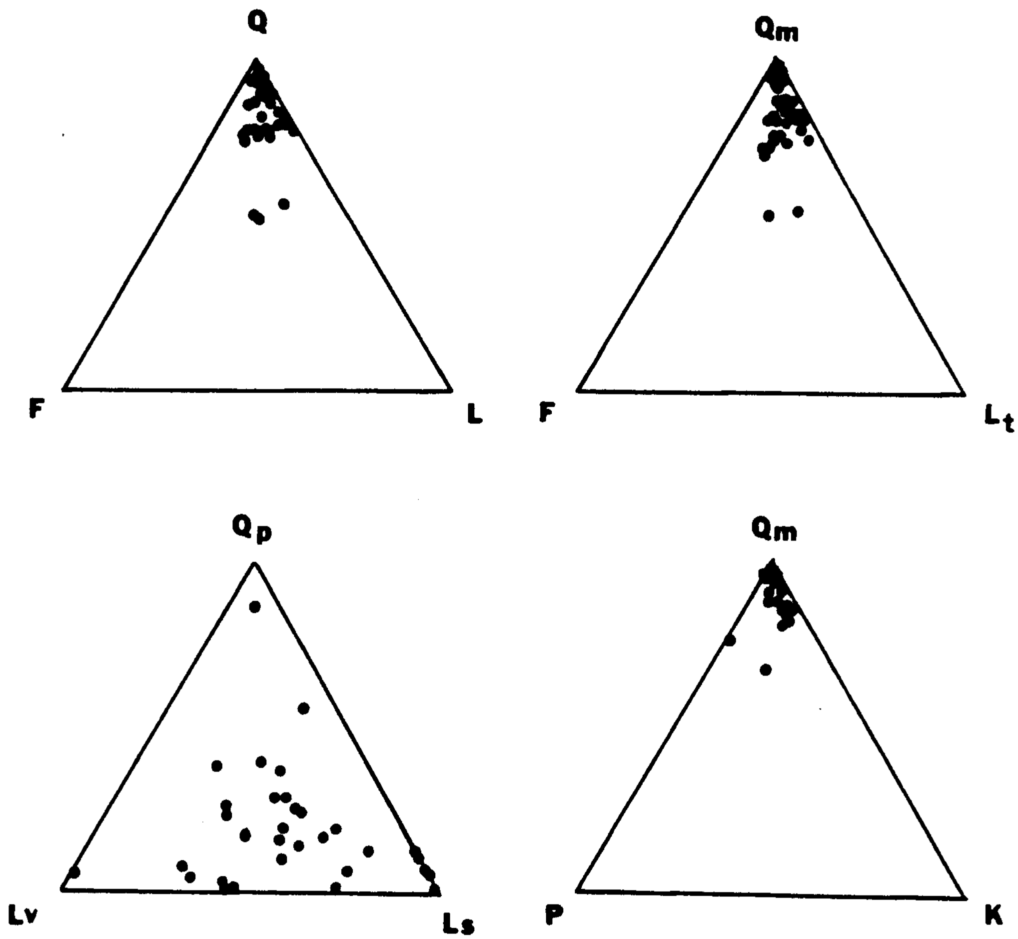

Figure 11 Triangular plots of Morrow sandstone samples

and associated platform successions (Dickinson and Suczek, 1979). Others plot in the recycled orogen provenance, particularly the foreland uplift and collision orogens. The key source rocks for these provenances, according to Dickinson and Suczek (1979) are recycled detritus of sediments or metasediments on uplifted terrains of folded and faulted strata. The QmFLt plot and the QmPK diagrams give the same information as the QFL plot. The QpLvLs plot shows a wide scatter of points, many of which do not fall in any described field and are, therefore, of limited use. Some points, however, do fall in the magmatic arc field of the diagram reflecting the presence of volcanic grains in those samples.

Problems Related to Provenance Studies

Several factors influence provenance studies of sandstones. These include: the tectonics of the source area, especially the erosion rate; climate in the source area, area of transport and site of deposition; length of transport both in distance and time; mode of transport and depositional environment; diagenesis of the sandstone; and the reltive grain size of the sample. All of these factors may have modified the framework composition of the Morrow sandstones relative to their source area.

The tectonics of the area have been discussed in a previous chapter. Higher relief usually results in a faster rate of erosion and less likelihood for weathering of the sediment before it enters the transport system. Low relief usually is accompanied by a slower erosion rate, the development of soil and in situ weathering of the sediment before it is transported.

Paleo-reconstruction maps of Scotese et al (1979) show that the study area and most of the probable source areas were near the equator prior to and during Morrowan time (Figure 12). The presence of coals in the Morrow Formation indicate that the climate was humid. According to Franzinella and Potter (1983), tropical weathering eliminates quartzo-feldspathic rock fragments more rapidly than it does quartz. The abundance of quartz relative to lithics in the Morrow may, therefore, be in part the result of a tropical climate. Suttner and Dutta (1986) considered the tectonics of the source area to be more important than climate in most provenance studies.

Sands can be extremely modified during transportation to their depositional site. Abrasion against other grains can cause polycrystalline grains to be reduced to their monocrystalline

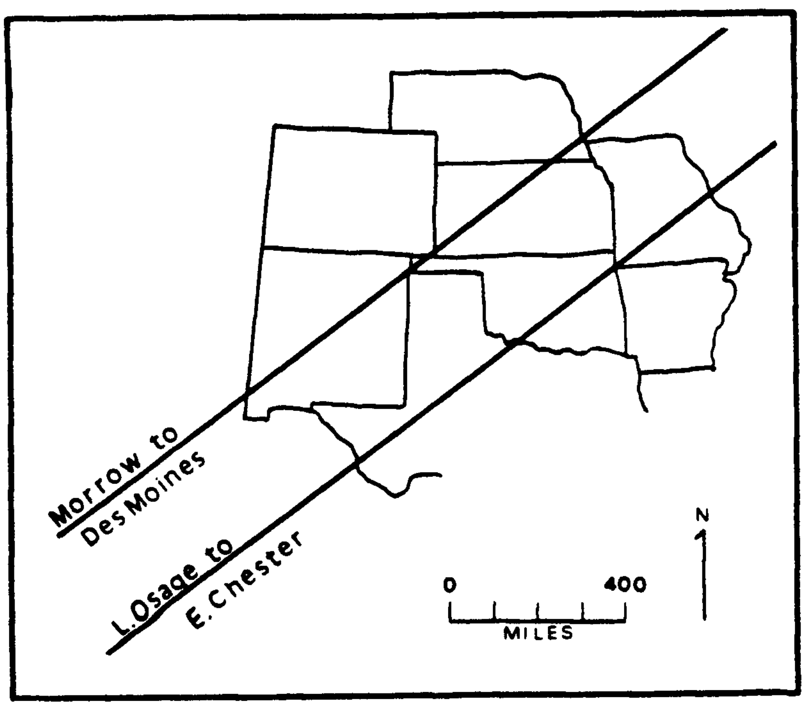

Figure 12 Approximate location of the equator during Morrow time (modified from Scotese et al, 1979).

components. Softer grains may be totally removed. The longer a grain is in route to its final depositional site, the more it is susceptible to destruction. Transportation by wind is more abrasive to grains than by water, because in water, each grain is coated with a thin film of water which slightly insulates the grain from abrasion. The depositional environment involved can allow a grain to be transported relatively directly to its site of deposition, or it may trap the grain in an abrasive cycle such as wave action near a beach or migrating sand dunes, for a substantial length of time before it is finally deposited. A grain may undergo several modes of transport, be deposited and eroded numerous times before it is finally deposited, lithified and buried. A quartz rich sand may be the result of long transport distance and the type of depositional system involved more than of its source area.

Diagenesis of a sandstone begins shortly after deposition and continues until the sandstone is exposed and eroded away. These physical and chemical changes are the result of changes in pressure, temperature and interstitial water chemistry. The stability of grains generally is related to the grain's position on the Bowen's Reaction Series and any physical imperfections it may have. Diagenesis may selectively remove particular grains such as feldspar or rock fragments, leaving more stable grains such as quartz. The presence of secondary porosity, framework grains floating in authigenic cement, framework grain size patches of clay or zeolite and the remnants of etched or corroded grains are good indicators that at least some of the original framework grains have been removed. Many of the sandstones observed in this study had one or more of the above indicators.

The relative grain size of a sample may influence the results of a provenance study. Smaller size fractions are typically composed of more stable grains that have better withstood the abrasive action during transportation. Data from very coarse samples may be skewed because substantially fewer grains will fit on a standard thin section resulting in the counting of less data points. Many authors, including Decker and Helmold (1985), suggested that grain size effects can be controlled by analyzing only samples with a mean grain size in the medium to coarse sand range. Only 10 of the 37 samples studied fell within this range, but the results are the same for all samples.

Diagenesis

Authigenic minerals are present in most of the sandstone samples examined in this study. Quartz overgrowths are present in 33 of the samples, calcite cement in 29, kaolinite in 20, dolomite cement in 18, pyrite in 12, clay cutans (possibly chlorite) in 7, a low birefringent cement (possibly zeolite) in 2 and hematite in one sample. Secondary porosity can be observed in at least 10 samples (Table 7).

Quartz overgrowths are euhedral and clearly authigenic in most samples. At least three samples, however, contain both euhedral and abraded quartz overgrowths. Abraded grains are considered to

Table 7 Diagenetic data for Morrow sandstone samples

SAMPLE	TOTAL COUNTS	K	P	VRF	CLAY CUTAN	QOC	KOA	CAL CEM	DOL CEM	PYR	ZEO?	2ND POR	FOS	GLAU
TW 5184	534	7	1			6		110	7	3			64	3
TW 5214	524	7	1			1		210					91	
LL 4868	528	7				8		139	1				36	1
LL 4906	206	3												1
CR 5025	403	24	2			1			1					
CT 4776	526	2				30								
ST 5380	520	6	4			74		72	1	8				37
AM 5667	506	2					1	203	1	3			5	1
IB 5735	385	6				20						3		10
IB 5754	217	3			2	9		38						2
IB 5758	362	1				9		53						4
NA 6051	397	6				6		3					34	28
NA 6071	392		1			15		9					43	20
GA 6010	356	9				3	2	54	51				40	19
GA 6029	376	3	1		4	9		10	1	4		1		22
LG 5370	404	5	2			10	12							
LG 5372	373	5	1			10	63	1	8					
LG 5373	375	6	3			12	69	12						
LG 5373	392	5				5	11		2	1				
LA 5615	375	14	1		9	16	1	9		1			5	10
LA 5641	388	8				10	6	10	7	1		5	4	10
AJ 5048	521	1	59	28		20	20				1	25		
AJ 5052	445	2	77	19		17	22		20			39		
WD 4484	388	34	11				20	2						3
WD 4491	352	34	4			7	35	1						
WD 4482	358	2	1					295						4
IP 5933	378	1			10	5	1	56		1			17	22
IP 5937	359	3	4			10		16					10	26
IP 5940	379	4	2			23		1	33			21	16	16
IP 5945	359	2	3		2	28		17				14	10	10
CW 5128	517	24	15			35		22	10				23	21
CW 5143	540	28	4			5	1	126					39	21
C- 5102	541	30	8	2		1	1	80	5	1			9	25
C- 5120	538	39	8	1		16	5	91	18			4	2	31
CK 6247	524		22	11		1	9	139	17	3			3	17
CH 4684	510	11	17	1	3	26	20	1	74			4		38
CH 4692	518	11	21	3		1	3	116	18	1		2	8	18

be indicative of a recycled sedimentary sand grain. In some samples the quartz overgrowths have substantially reduced the intergranular porosity.

Calcite cement is the most common carbonate cement in the samples. It usually is associated with marine fossils in the sample. In some thin sections, the fossil appears to be the nucleus of the poikolitic calcite cement. In many samples, the calcite cement is very widespread engulfing all framework grains and eliminating porosity. The calcite cement appears to be replacing grains in many samples. In some thin sections, 50% or more of the data points are calcite cement which may cause misinterpretations of lithologies from well log response.

Grain size patches of kaolinite are present, at least to a minor extent, in over half of the samples studied. Seven of the volcanic rock fragment bearing samples contain kaolinite in small to moderate amounts. A few of the nonvolcanic bearing samples contain 10% to 20% kaolinite. The presence of kaolinite usually is a good indicator that some of the original feldspar grains have been removed.

Dolomite cement is less common than calcite, but both frequently are found in the same sample. The dolomite does not seem to be associated with fossil material. It is more of an isolated, pore filling cement, although it does appear to be replacing glauconite in some samples.

Secondary porosity clearly is evident in 10 samples including five of the seven volcanic rock fragment bearing samples. Partially dissolved feldspar are present in several samples, which indicate that the secondary porosity may have originally been feldspar framework grains.

A general diagenetic sequence appears to begin with the formation of clay cutans followed by quartz overgrowths. The clay cutans observed did not form on any quartz overgrowths and in the same sample the quartz overgrowths only are present on grains free of clay cutans. The quartz overgrowths clearly predate both the kaolinite and calcite cement. Kaolinite appears to predate the calcite cement in at least a few of the samples. Dolomite cement and pyrite appear to be relatively late diagentic features. Evidence for the timing of the secondary porosity, zeolite (?), and hematite was not observed.

Potential Source Areas

Figure 13 shows the paleogeographic features present in the region around the study area during Morrowan time. To the west the Ancestral Rocky Mountains, predominantly composed of Precambrian gneisses and granites, were in the early stages of uplift. The Central Kansas Uplift was a positive feature in the east exposing older sedimentary strata, predominantly carbonates, to erosion at this time. To the north was the Transcontinental Arch (also called the Frontrangia-Siouxia uplift by Swanson, 1979). The arch was a positive feature through the Mississippian upon which windows of Precambrian metamorphics were exposed by the erosion of its Paleozoic sedimentary rock cover. The Keyes Dome was a minor structural feature in the southwestern corner of Kansas and panhandle of

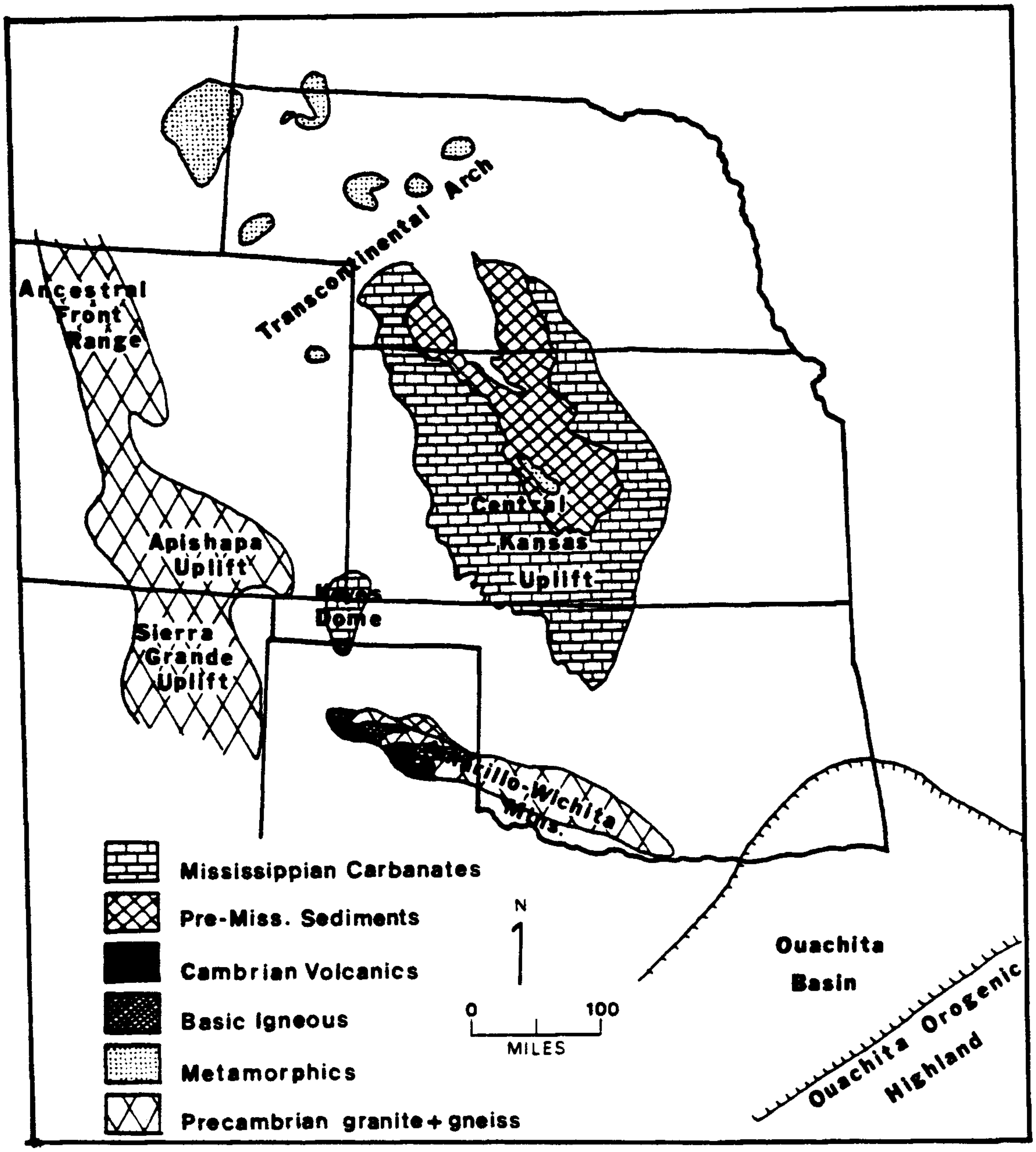

Figure 13 Potential source areas for Morrow sandstone (modified from DeVoto, 1980 b; Fogotson, Stalter & David, 1966; Kluth & Coney, 1981; Owen & Carozzi, 1986; Swanson, 1979; and Tweto, 1980).

Oklahoma (Huffman, 1959) which may have shed detritus from older Paleozoic sediments into the basin during the beginning of Morrowan time, but was subsequently buried by Morrowan sediments. The Amarillo-Wichita Mountains may have been uplifted in the panhandle of Texas and southern Oklahoma during Morrowan time, exposing Cambrian volcanics and other intrusive igneous rocks and pre-Mississippian sediments, but several authors (Ham and Wilson, 1976; Huffman, 1959) consider them to be post-Morrowan features. To the southeast of the study area, where Texas and northern Louisiana are today, was the Ouachita orogenic highland. This is the only known location of active volcanism in the region during Morrowan time.

Conclusions

Most of the Morrow sandstones studied are quartzose sands. Seven samples from four wells contain volcanic rock fragments. The quartzose grains had an entirely different source area than the volcanics, and are treated first.

Quartzose grains

The quartzose Morrow sandstones were largely derived from erosion of older Paleozoic sedimentary units in the craton interior This is primarily supported by the Dickinson-Suczek method of statistical evaluations and triangular diagrams. The presence of abraded quartz overgrowths in some samples and chert in most samples further substantiates this interpretation.

The extensive erosion and karst development that took place during the late Mississippian could have released numerous thin sandstones present in the predominantly carbonate Paleozoic strata. These sands were collected and deposited by the Morrow fluvial-deltaic systems. The proximal location and positive relief of the Central Kansas Uplift to the study area make it the most probable primary source of Morrow sands. If the Precambrian core of the ancestral Rocky Mountain Uplifts or the exposed shield of the Transcontinental Arch had been the primary source, the Morrow sandstones would contain substantially higher amounts of feldspar and quartzo-feldspathic rock fragments. They may have been a minor source to southwestern Kansas during Morrowan time.

Many of the samples plotted in the recycled orogen provenance, particularly the foreland uplift and collision orogen portions of the triangular diagrams. These provenances were not present as potential source areas to southwestern Kansas. Dickinson and Suczek (1979) characterize sands from these provenances as recycled detritus of sediments from uplifted terrains. This author suggests that these sands are indeed recycled, but that they are the result of extensive erosion instead of sediments from uplifted, folded and faulted terrains.

Extensive carbonate cementation, replacement of grains and other diagenetic activity may have removed feldspar, which would have skewed the data away from the Ancestral Rockies as the source of the sands. The uplifted basement plots on the QFL and QmFLt diagrams of Dickinson and Suczek (1979) are shown to contain 30%

to 60% feldspar. It is volumetrically impossible to add this much feldspar to the samples studied.

Volcanic Bearing Sandstones

The volcanic rock fragment bearing sandstones are from Morton County. All of these samples have larger amounts of plagioclase than the other samples studied. Elevated plagioclase levels also are present in two additional Morton County wells (Table 8) suggesting that minor amounts of volcanic rock fragments may have been deposited in them, but were not observed during the point count procedure. These sections were borrowed from the Kansas Geological Survey and were not stained for feldspar. In these sections, many of the grains counted as chert may actually be a microcrystalline feldspar type volcanic rock fragment, and many of the untwinned feldspars counted as potassium feldspar may actually be plagioclase grains.

The sandstones studied from these six wells are from two stratigraphic horizons, a lower Upper Morrow sandstone and an upper Lower Morrow sandstone (located immediately below the Chester East marker). Samples from two other Morton County wells show no evidence of volcanic rock fragments, only minor amounts of plagioclase and small amounts of potassium feldspar. The samples from these wells are from different stratigraphic positions than those mentioned above. This indicates that volcanics were introduced into the Morrow depositional basin at two distinct time invervals, not continuously.

Table 8 Summation of Morrow County samples

SAMPLE	LOCATION	K	P	VRF	STRATIGRAPHIC INTERVAL
AJ	9-33S-40W	1%	40%	13%	lower Upper Morrow
WD	19-33S-42W	44%	10%	--	lower Upper Morrow
CT	5-35S-41W	37%	14%	--	upper Lower Morrow
C-	5-35S-41W	42%	9%	2%	upper Lower Morrow
CK	13-35S-41W	--	36%	3%	upper Lower Morrow
CH	11-35S-42W	17%	30%	3%	upper Lower Morrow
LG	6-33S-40W	11%	3%	--	lower Lower Morrow
LA	8-33S-40W	10%	1%	--	middle Lower Morrow

K = potassium feldspar, P = plagioclase feldspar, VRF = volcanic rock fragments. Percentages are relative to the total amount of feldspar and lithics for all the samples from each well.

The fresh appearance of the volcanic rock fragments plus their limited occurrence in the section, suggests that they were derived from active volcanoes. The volcanic rock fragments are composed of chert-like (possible cryptocrystalline plagioclase) rounded fragments with phenocrysts of plagioclase. The only active volcanism in the region was associated with the Ouachita-Marathon orogenic highlands forming to the southeast. The volcanic rock fragments are from medium to very coarse sand in size. They must have been carried to the study area by wind since a large depositional basin (the Anadarko Basin) separated south-western Kansas from the volcanoes. The intermittent deposition of the volcanics in the study area could have been associated with a few major eruptions that scattered debris over an enormous geo-graphic area. Swanson (1978) showed the presence of volcanics in Upper Morrow sandstones in Baca County Colorado and Texas County Oklahoma. A study of Morrow sandstones in the Anadarko Basin of Oklahoma could verify the source of the volcanics as coming from the Ouachita-Marathon orogenic highlands, if the amount of volcanic rock fragments and plagioclase increased toward the southern portion of the state.

logs from Lane Wells logging company were run on numerous older wells in Meade and Clark counties. They consist of the old style gamma ray curve described above in the left track and an old style, jagged neutron curve in the right hand track. Both of these well log types could be used for correlation purposes with some difficulty. Some lithologic information can be interpreted from the laterolog surveys, but the radioactivity surveys are of little value in this regard.

Formation Tops

Formation top information from available completion cards was used initially to correlate the top of the Morrow, Chester and St. Genevieve formations on logs. The author is familiar with the criteria used by Amoco Production and some smaller companies in picking tops from well logs in the area. The well log types available in Clark and Meade counties made picking consistent tops difficult, so an additional 150 to 200 logs were used to help correlate across townships in those counties.

Morrow Formation

The top of the Morrow Formation is relatively easy to identify and consistently picked by most workers in the area, as shown by completion card data. It is found immediately below the Thirteen Finger Limestone of Atokan age. This formation, as the name implies, consists of numerous thin limestones separated by thin shales.

Chester Formation

Placing the top of the Chester on well logs is very

CHAPTER 5

REGIONAL CROSS SECTIONS AND MAPS

Method of Study

To identify the Morrow-Chester boundary from well logs by some consistent method, well logs were used to construct a grid of nine east-west and four north-south cross sections over the study area (Figure 14) (Plates I, II, III, IV and V). These stratigraphic sections are hung from the top of the Morrow since up to 3100 ft. (945 m.) of relief can be found on a single

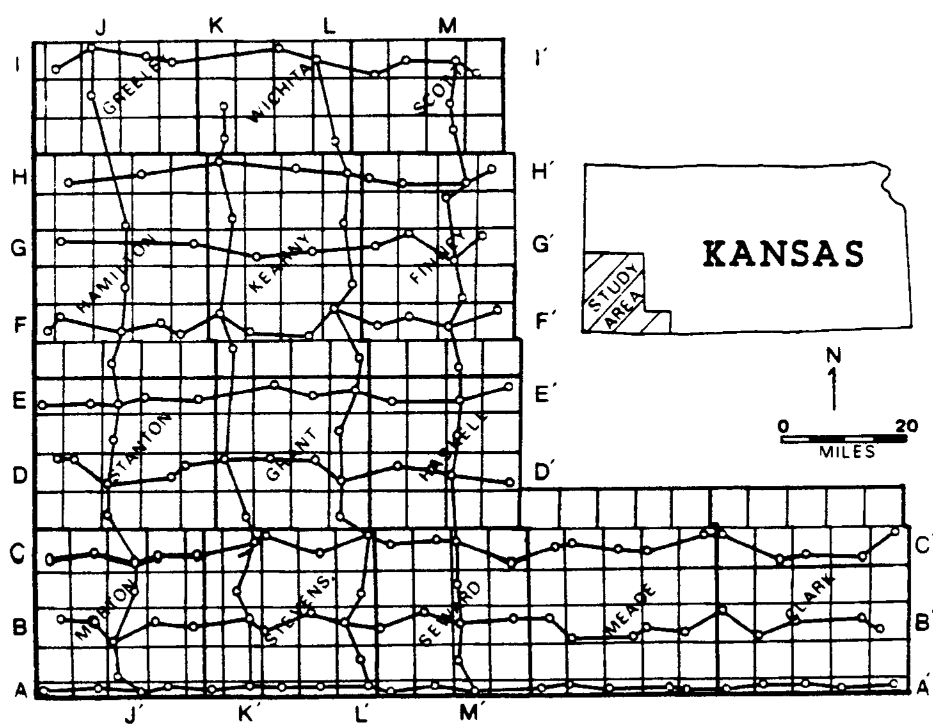

Figure 14 Location of cross section lines

cross section line, making structural cross section impractical. An attempt was made to use one well log per township. Logs that go through the entire Morrow section and on into the St. Genevieve (Meramecian) were preferred over those that only penetrate part of the Morrow. Logs from deep wells are easy to obtain for the southern part of the study area, but numerous northern townships either do not contain deep wells, or the deep logs are no longer available. Where logs are missing, correlation lines are dashed to signify that the exact thickness and structural position of the horizon are not known in these areas. Logs for wells from which core was examined in this study were used whenever possible, but many of these wells did not penetrate the entire section. Depths and thicknesses of units are given in feet since the petroleum industry in North America uses the English system of measurement. Logs were obtained from Marathon Oil Company's Denver Research Center, the Kansas Geological Society in Wichita Kansas, and Petroleum Information in Denver.

Three regional maps, two structural and one isopach, were constructed for the study area. The top of the Morrow and top of the St. Genevieve structural maps show variations in elevations for these horizons. The top of the Morrow to top of St. Genevieve, Morrow-Chester, isopach map shows regional thickness variations for the interval. Data for these maps was calculated from formation tops identified on well logs. These tops were correlated with the tops used on the regional cross sections. Approximately 240 well logs were used for this purpose. They include logs found on the regional cross sections, logs representing wells from which core was examined in this study, and logs from as many townships not previously represented as possible. Elevations on the structure maps are relative to sea level and were calculated using the depth datum given on the log header. Not all logs give a depth datum. Data from these logs could not be used for the structural maps, but could be used for the isopach map. The locations of faults in Morton County were delineated by using logs from over 175 wells to construct a more detailed top of the Morrow structure map for that county.

Well Logs

The ideal log used was one that is dual induction in nature with a spontaneous potential (SP) curve in the left hand track and resistivity curves in the right hand track. It penetrated the top of the Morrow and went down through the St. Genevieve, and was available in the scale one inch equals one hundred feet (1" = 100'). Well logs available only in larger scales were drafted to 1" = 100'. Well logs meeting these ideal criteria were not available in many areas, especially in Meade and Clark Counties.

Over the 40 years that Morrow wells have been drilled in the study area, well logging technology has greatly improved. In some areas, old well logs are the only ones available. Schlumerger's laterolog surveys frequently were run in older wells in the area. They have an old style gamma ray curve in the left hand track and a laterolog curve, frequently accompanied by a microlaterolog curve in the right hand track. The old style gamma ray curves are very erratic, going off track at ever slight change to shale, and are very jagged. The laterolog curves are the precursors to resistivity curves and are similar in principle, but are jagged in appearance. Radioactivity subjective. By comparing completion card tops for the Chester along the three most southern cross sections (A-A', B-B' and C-C') (Plate I), it is apparent that two different horizons are denoted as the top of the Chester. The top commonly used in the eastern part of the study area, referred to here as Chester East, is substantially higher than the one more commonly picked in the western part of the Hugoton Embayment referred to here as Chester West. The Chester West is a basal unit that directly overlies the St. Genevieve. Its top is similar to the tops used by Amoco. Production. All of the core examined in this study were classified as Morrow by the well operator and the Kansas Geological Survey's core library list, but many of them lie below the Chester East correlation line. The most frequently picked horizon for both the Chester East and the Chester West was used to correlate across the area, although it should be noted that completion card tops often vary from these two correlations.

Some completion cards give the top of the Misssissippian without identifying whether the company considered the strata to be Chester or St. Genevieve. This is of particular concern near the Chester pinch out in the central part of the study area. In southern areas, the tops labeled Mississippian can be assumed to mean Chester.

Both the Morrow and the Chester are bounded by unconformities. They are composed of genetically similar rocks with similar log character whose main difference is age. To accurately determine the top of the Chester, a regional paleontology study accompanied by regional cross sections would have to be done. In

Oklahoma's Anadarko Basin, the Mississippian section is more complete than in the Hugoton Embayment. The uppermost Mississippian unit is Springer in age. It is genetically related to the overlying Morrow. Since the two are almost impossible to separate from well log data, the term Morrow-Springer is used to refer to the rocks. In the Hugoton Embayment, most authorities assume that the Springer is absent, resulting in an unconformity separating the Morrow from the Chester. Since the Morrow and Chester are difficult to distinguish between in the subsurface in the study area, they should be considered as one unit, the Morrow-Chester Formation, even though they are different in age.

St. Genevieve Formation

This study has adopted the common practice within the petroleum industry of referring to the first massive limestone below the Morrow-Chester rocks as the St. Genevieve Limestone. Since this is an erosional boundary, paleontology studies may prove these rocks to actually be of older Mississippian age in places.

Top of the Morrow Structure Map

The top of the Morrow structure map (Plate VI) is contoured on a 100 ft. (30 m.) interval. Except in the area of Keyes Dome in Morton County, the top of the formation is shallowest on the west and north and deepens to the south and east. In the northern half of the study area, the structure is relatively flat with a few broad noses, especially in Kearny County. The top of the Morrow begins to deepen rapidly to the southeast in the counties along the

Kansas-Oklahoma state line. Depths vary across the map from -1191 ft. (-363 m.) in the northwest (T18S R42W) to -3574 ft. (1090 m.) (T35S R35W) in the southeast. The shallowest depth is in the area of Keyes Dome at -493 ft. (150 m.) (T35S R43W).

Three semiparallel fault systems are located in Morton County. They were delineated by a more detailed top of the Morrow structure map of that county (Figure 15). Similar faults are present on a Kansas Geological Survey map of the Precambrian (Cole, 1976). These fault systems have some expression in the Permian of Morton County (from personal experience in the petroleum industry), indicating that their latest movements are post Permian in age. The faults may have bounded the Keyes Dome on the east side.

Morrow-Chester Isopach Map

This isopach map is contoured on a 50 ft. (15 m.) interval (Plate VII). It shows a general thickening of units toward the west and south, indicating that the Morrow depositional-erosional boundary on the east was affected by the Central Kansas Uplift. A sudden thickening of the unit in a few townships in central Morton County correlates with the fault locations, suggesting that portions of these faults were active during Morrowan time. In other areas, local thickening may be related to solution features on the top of the St. Genevieve limestone or to minor local faulting. More detailed mapping around these areas may help determine why they occur. The well in T27S R35W is the most prominent of these sudden thickenings. The well log for this well can be found on cross section E-E' (Plate II).

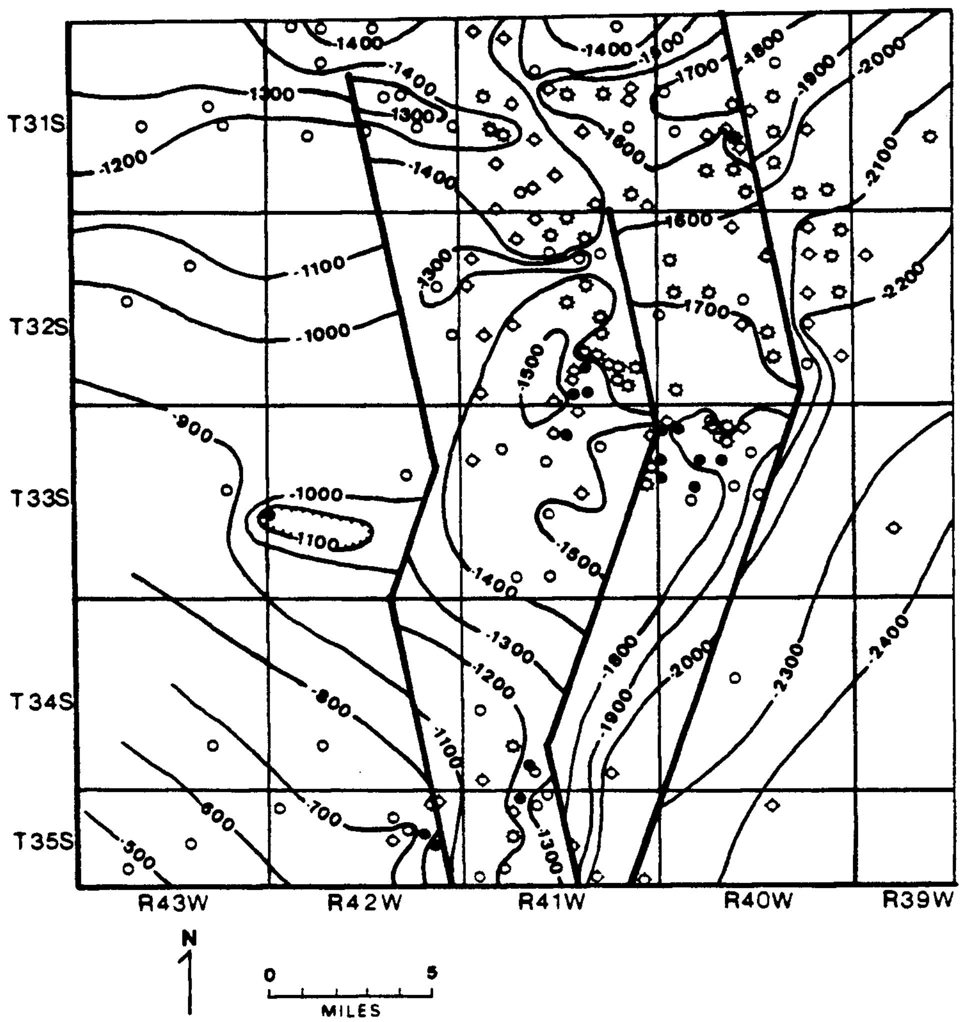

Figure 15 Top of Morrow structure map for Morton County

Figure 16 shows the approximate pinchout lines for both the Chester East and the Chester West units. Except in Clark County and a few minor noses in other areas, the two pinchout lines are very similar in location. These Chester pinchouts are not evident in thickness trends on the Morrow-Chester isopach, further supporting the argument that these units are genetically related and for practical purposes should be treated as one unit that stradles the systematic boundary.

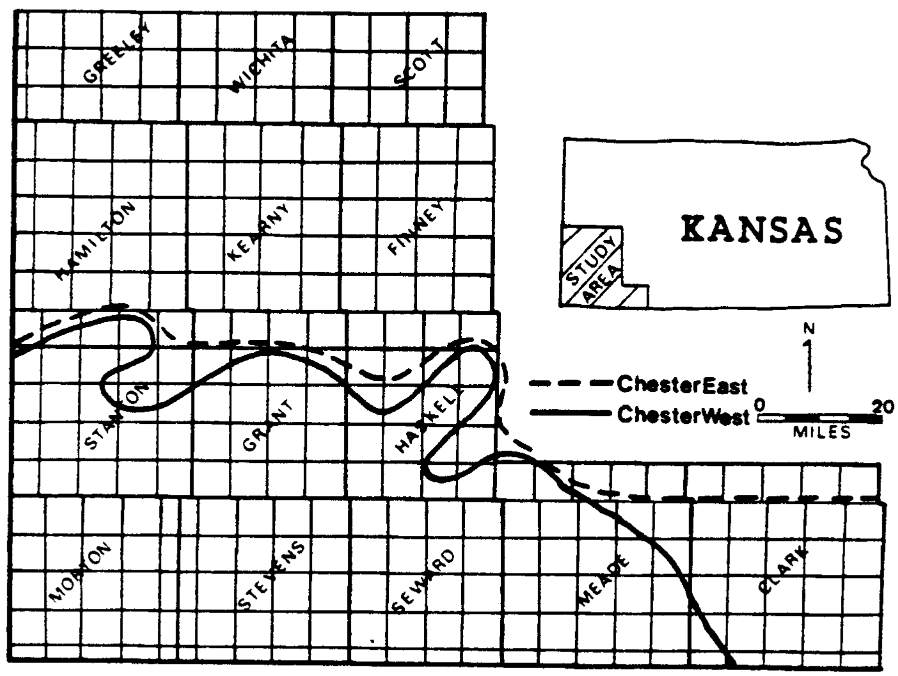

Figure 16 Location of Chester pinch out

<u>Top of the St. Genevieve Structure Map</u>

The top of St. Genevieve structure map (Plate VIII) is contoured on a 100 ft. (30 m.) interval. It is similar to the top of the Morrow structure map with shallowest elevations on the west and north and deeper ones on the south and east, except in Morton

County. The difference in elevation between the west and the east is much less on the St. Genevieve map than on the Morrow one. This would account for the thickening of the Morrow-Chester isopach toward the west. The fault systems are evident in Morton County as is the expression of the Keyes Dome. As previously mentioned, the top of the St. Genevieve is much lower in the well in T27S R35W than in surrounding wells. Again, this may be the result of solution features (sink hole ?) or a minor fault in that vicinity. Like the Morrow, the top of the St. Genevieve deepens rapidly toward the south in the counties along the Kansas-Oklahoma border.

CHAPTER 6

DEPOSITIONAL ENVIRONMENTS

Introduction

Twenty-four Morrow cores from the Kansas Geological Survey in Lawrence, Kansas, (Figure 17) were examined and described to determine the type of depositional environments that were present in the study area during Morrowan time. Summarized core descriptions were correlated with well logs for 23 of the wells and have been placed in the Appendix. No logs could be obtained for one of the

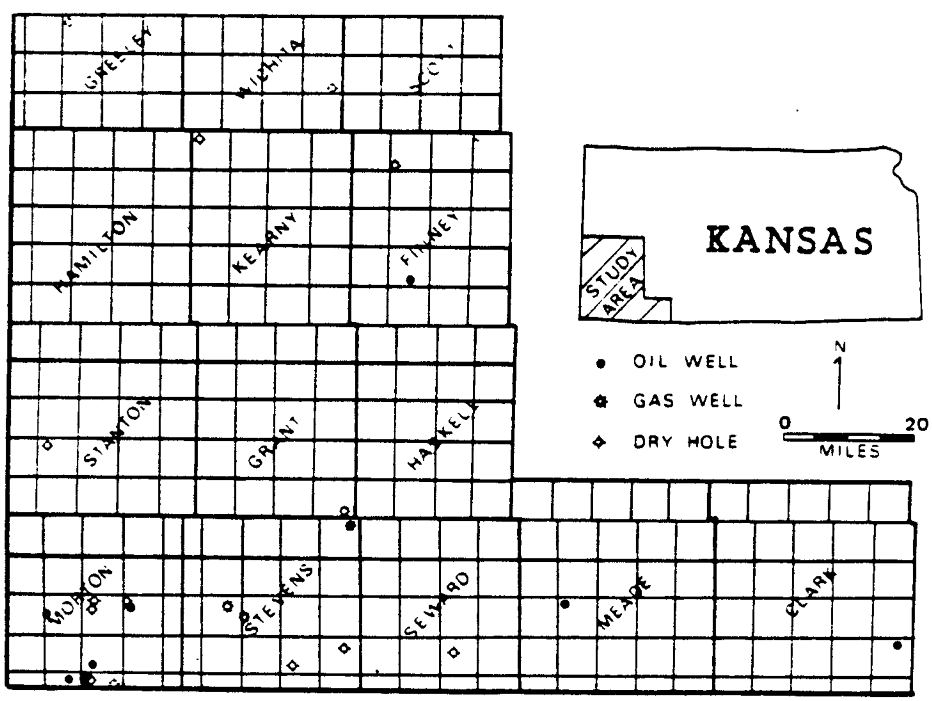

Figure 17 Location of Morrow cores studied

cored wells. The correlations are useful both in placing each sand in its relative stratigraphic position and in relating the log response to the environment of deposition.

During early Morrowan time, a normal marine shallow sea transgressed across the study area from the Anadarko Basin in the south, depositing marine strata. This included the deposition of shales, thin limestones and storm generated sandstones. The northern portion of the study area probably was not covered by the sea at this time.

By middle Morrowan time the epicontinental sea had regressed from the area. Meandering fluvial and fluvial dominated deltaic systems were established covering the entire study area. These environments were active in southwestern Kansas until the end of Morrowan time.

Epicontinental Seas

The term epicontinental or epeiric sea can be used to describe the marine water bodies that intermittently occupied the study area during Mississippian and Pennsylvanian time, including early Morrow time. These seas were shallow and warm. Hallam (1981) in his chapter on epicontinental seas concluded that: 1) tidal range in such seas is close to zero, 2) effectively, the only wave energy would be those generated by local winds, and 3) restricted circulation is common to epeiric seas. These conclusions, if valid, are important when interpretating depositional environments for the lower Morrow Formation of southwestern Kansas.

In shallow epeiric seas, tides are reduced by friction from the bottom which can reduce tidal range to almost zero (Hallam, 1981).

In ancient deposits it is difficult to distinguish between tidal current deposits and storm generated deposits (Galloway and Hobday, 1983; Hallam, 1981). This suggests that the influence of tide on Morrow sandstones can be assumed to be negligible and that deposits that have characteristics of tidal action probably were deposited by storms. It should be noted that Galloway and Hobday (1983) believe that broad shallow shelves and shallow profiles increase tidal range in some areas.

A low oceanward gradient of an epeiric sea bed can mathematically be shown to result in a condition where waves generated by wind some distance offshore will dissipate their energy before reaching the shore (Hallam, 1981). This suggests that wave activity in the study area would have been the result of local winds. The equator's proximity to the area during Morrowan time (Scotese et al, 1979) could mean that trade winds would have had more of an effect on the depositional systems in the area than Hallam's generalization implies.

The extreme shallowness of the water over large areas could result in minor topographic irregularities of the sea bed effectively restricting circulation of the water (Hallam, 1981). The low tidal range and restricted wave activity would further reduce the circulation.

Recognizing Depositional Environments from Core

Having a basic understanding of the depositional environments that may have been active in an area is an important first step in trying to determine the environment represented by core samples. Information on grain size, sorting, lithologies, bedding types, fossils, bioturbation, etc. can be obtained from core. Well logs may help identify associated lithologic sequences above and below the cored interval. All of this information can then be used to identify the depositional environments represented. Detailed subsurface mapping, especially net sand maps, may help delineate the geometry of a particular unit of interest. The map view geometry of a sandstone package may be crucial in determining precisely which environment is represented by the core. Unfortunately, detailed mapping around the cored wells was not possible in this study because of well log availability constraints.

The depositional environments thought to have been active in the area during Morrowan time were fluvial, deltaic and shallow marine. Tidal sands and barrier islands were probably not present during Morrowan time, and were not identified in the samples studied. The environments can be broken down into individual facies (Table 9) which have characteristics that can be used to identify them in core samples. The following is a brief summary of those facies.

Table 9 Clastic environments present in Morrow core studied.

FLUVIAL	DELTAIC	SHALLOW MARINE
point bar channel fill crevasse splay levees flood plain	point bars channel fill crevasse splays levees interdistributary areas channel mouth bars delta front prodelta mud	shelf muds storm generated sands

Point Bar

Point bar deposits are found in both meandering fluvial and deltaic environments. They are upward fining, clastic deposits with small to large scale cross stratification; wavy, irregular, rippled, tabular, planar and convolute bedding; and occasional burrows. The basal contact is sharp and erosional, the upper contact grades into flood plain or backswamp marsh No fauna usually is present, but plant material may be common with large blocky, woody fragments frequently concentrated near the base.

Channel Fill

Channel fill deposits of both meandering fluvial and deltaic distributary types are commonly encountered in Morrow sandstones. The vertical sequence of channel fill deposits may resemble a point bar deposit with an overall upward fining change in grain size; sharp basal contact; gradational upper contact with flood plain or back swamp marsh; plant debris; and cross stratified, wavy, rippled, convolute and inclined bedding. Other channel deposits may contain thick sequences of finely laminated mud intercalated with generally cross bedded sandstone. Swanson (1979) stated that it is difficult to distinguish channel fill deposits from backswamp marsh deposits without knowing what lateral facies are present.

Crevasse Splays

Crevasse splays are thin sandstone units deposited during flood stage when the natural levees of the river or distributary channel are breached allowing overflow into the adjacent flood plain or interdistributary area. They are composed of alternating beds of sand, silt and clay which have a general decrease in grain size away from the channel. The sandstones usually are flat bedded with microscopic cross laminations, commonly contain highly macerated vegetable detritus that imparts a dark color to certain bedding planes, and may be one to five feet thick (Wanless et al, 1970). Splays are coarser grained than levee deposits, commonly contain scour and fill structures and are generally capped by mud sequences (Reineck and Singh, 1975).

Natural Levees

Natural levees are wedge-shaped ridges located on either side of a channel. Their repeated cycles of upward fining clastics are terminated by mud layers. They generally are finer grained than point bars, but commonly grade into the upper portion of adjacent point bar deposits. Small scale cross stratification, climbing ripples, and horizontal, parallel laminations are the bedding types commonly associated with natural levees (Reineck and Singh, 1975). Root disturbed zones, highly leached zones, nodules and concretions are commonly associated with levees (Galloway and Hobday, 1985).

Flood Plain

Flood plain facies contain fine grained clastics that are similar to crevasse splays and levee deposits. Swanson (1979) placed flood plain deposits in his backswamp marsh facies which also included interdistributary areas of deltas. Bedding usually is even and horizontal with some wavy irregular beds. Rootlets and burrows are common. Interdistributary bay deposits may contain abundant shell debris and glauconite (Miall, 1979).

Stream Mouth Bar and Fan

These deposits also are called channel mouth bars and are deposited where the distributary channel of the delta enters a standing body of water. This results in a sudden decrease in stream flow velocity which causes the bed load to be dropped. These sandy shoals are continually reworked by both stream currents and waves and are composed of coarsening upward sequences of sand and clay that fine seaward. Trough cross bedding, wave and current ripples, graded beds, convolute and slumped beds are typical. The basal contact is gradational, often as intercalated beds of prodelta clay and sand. The upper contact usually is sharp and may contain truncated beds. These sandstones may be overlain by anything from backswamp marsh to prodelta clay or even point bars. No fauna are found in these deposits, but thin lamina of carbonaceous plant debris may be present.

Delta Front

The delta front sands, also referred to as distal bars, are comprised of intercalated fine sand and clay with some silt. They coarsen upward, are evenly laminated, and contain graded, cross stratified, current rippled, parallel laminated and lenticular bedding with some scour and fill structures. Small burrows and zones of shell debris may be present, especially in the lower part of the bar, but these sands are relatively free of carbonaceous material. Distal bars are made from distributary mouth bar sands that have drifted laterally due to wave activity (Reineck and Singh, 1975). They grade upward into a variety of environments and downward into offshore shallow marine mud.

Prodelta Muds

Prodelta muds are derived from the delta and are transitional to the shelf muds. They commonly contain shelf debris, wood fragments and dispersed burrows. The high sedimentation rate tends to restrict the amount of bioturbation. Acidic pore waters may leach away shell material (Galloway and Hobday, 1983). Slumped and contorted bedding, isolated lenses of sandstone and intraformational faults are common internal structures. These muds grade basinward and downward into shelf muds and upward into channel mouth bars, delta front sands or interdistributary environments.

Shelf Muds

The shallow marine shelf muds are similar to prodelta muds, but are deposited under a slower sedimentation rate which encourages widespread bioturbation. They also contain a wide variety of marine organisms. Evidence of the sedimentation rate and biological diversity are the best criteria for differentiating between shelf and prodelta muds. The main criteria used to recognize shallow marine sandstones is the presence of marine body fossils, trace fossils and glauconite.

Shelf Storm Sands

Shelf storm sands may be the result of erosion of deltaic deposits. Storm generated waves have been known to move sediment out to water depths of 650 ft. (198 m.) (Galloway and Hobday, 1983). The storm sandstone facies usually have a basal shelly lag, may be highly bioturbated, and grade into interlaminated sand and mud which in turn grade into homogeneous mud. They tend to have a sharp erosional base, but the upper contact may be sharp, gradational or bioturbated. Parallel laminations with some current lineations are the dominant internal structures, but shelf storm sands also may contain cross laminations, graded beds, or load structures. Each sandstone unit usually represents a single storm event (Reading, 1978). Transgressive shelf systems tend to be upward fining while prograding systems are upward coarsening or storm graded (Galloway and Hobday, 1983). Shelf sand wave and ridge deposits are largely tidal in origin and probably are not present in the study area.

Morrow Depositional Environments

The main depositional environments present in the study area during Morrowan time were fluvial, deltaic and shallow marine. The fluvial systems probably were of a meandering type since the land was vegetated and had a shallow slope. The deltaic systems were probably fluvial dominated which further supports the theory that wave and tide activity was minimal. Brown (1979) and Swanson (1979) conclude that the Morrowan deltaic systems in the Anadarko Basin also were fluvial dominated. If part of the coast had been wave dominated as a result of trade winds, barrier islands may have formed.

The Lower Morrow strata are considered to be shallow marine in origin. Cores from 13 of the wells used in this study contain lower Morrow shallow marine deposits (Table 10). Strata adjacent to or below the Chester East stratigraphic marker belong to this group. They typically contain marine fossil-bearing sandstone intercalated with marine shale. Glauconite is present in many of

Table 10 Lower Morrow shallow marine core

5 T18S R41W	Terrel Wheeler # 1
4 T29S R42W	Superior Tucker #1
36 T30S R35W	Anadarko McClelland B # 3
19 T 33S R37W	Anadarko Nell A # 1
10 T33S R38W	Anadarko Gaskill A # 2
8 T33S R40W	Anadarko Low A # 5
3 T34S R21W	Texas O & G Harper Ranch B # 1
28 T34S R36W	Mobil Parker Estate 3 - 4
5 T35S R41W	Cities Service WMS 3-205W
5 T35S R41W	Cities Service WMS 3-206W
13 T35S R41W	Cities Service Kniffen A # 2
11 T35S R42W	Cities Service Horton C # 3

these sandstones. Limestone is present in a few of the cores. Burrows and bioturbated zones are found in sandstone and shale facies. Zones of black barren shale are present in five of these wells. The sandstones are thin lenses to thick bars. The sandstone bars in Superior Tucker #1 and Anadarko Low A # 5 are clearly upward fining (see Appendix, p. 88 and p. 95). These shallow marine sandstones probably are the result of storm events. Large coral fragments (1 to 4 inches (3 to 11 cm.) in diameter) are present in Cities Service WMS 3-205W. They are clearly the result of storm activity since they are surrounded by medium to coarse grained, bioturbated sandstone.

Cores from 14 of the wells studied contain upper Morrow fluvial deltaic deposits (Table 11). The Anadarko Low G - 1 and Cities Service Heyen B - 1 contain sandstones that appear to

Table 11 Upper Morrow fluvial-deltaic cores

5 T18S R41W	Terrel Wheeler # 1
36 T19S R35W	Lauck Lehman # 1
31 T21S R33W	Shallow Water Maune # 4
5 T21S R38W	Cleary Rupp # 2
27 T24S R33W	Cities Service Tait C # 4
1 T31S R35W	Mobil Cutter # 1
6 T33S R29W	Imperial Boaln # 1
6 T33S R40W	Anadarko Low G # 1
4 T33S R41W	Cities Service Heyen B # 1
9 T33S R41W	Anadarko Jones B # 1
3 T34S R21W	Texas O & G Harper Ranch B # 1
16 T34S R32W	Lario Pennington # 1
33 T34S R41W	Cities Service Sutton B # 2
18 T35S R41W	Cities Service Daniels C # 1

either be point bars or distributary channels (Appendix, p. 94 and p. 96). Shallow Water Maune #4 and Anadarko Jones B - 1 also contain distributary channels (Appendix, p. 15 and p. 97). Channel mouth bars are represented in core from Cities Service Sutton B - 2 and Daniels C - 1 (appendix, p. 101 and p. 105). The remaining cores have strata that can be interpreted as interdistributary channel, flood plain, channel fill, levee or marsh with some possible crevasse splays.

Some of the facies identified above can be correlated on well logs from nearby wells. Brief descriptions of the cored intervals can be found on the sample well logs in the Appendix.

The core from the northern portion of the study area tend to be from the upper Morrow fluvial deltaic facies. The absence of lower Morrow and Chester strata from the northern portion of the study area suggests that these strata were not deposited in this area. The early Morrow shallow sea probably did not transgress the area. An extended period of erosion also could account for their absence.

Swanson (1979) wrote an excellent paper on the upper Morrowan sandstones in the Anadarko Basin. He outlined 7 types of deposits common to his fluvial and deltaic environments based on core and detailed subsurface mapping. His work agrees with environments of deposition found in the upper Morrow core of southwestern Kansas. Swanson's environment types are: 1) point bar, 2) stream mouth bars and fans, 3) distributary channel fill, 4) meandering channel fill, 5) back swamp marsh claystones and siltstone, 6) delta front, and 7) prodelta claystones. He used detailed subsurface mapping to better determine what environments were represented by his core samples.

Black Shales

At least 6 of the Morrow cores examined in this study have thin to thick black shale sequences (Table 12). Additional cores contain intercalated thin black shale with thin sandstone or siltstone. These shales often appear to be barren with no trace fossils or evidence of bioturbation and very few, scattered shell fossils or plant fragments. A micropaleontologic study, how-

Table 12 Cores that contain black shale

31 T21S R33W	Shallow Water Maune # 4
4 T29S R42W	Superior Oil Tucker A # 68
19 T33S R37W	Anadarko Production Nell A # 1
10 T33S R38W	Anadarko Production Gaskill A # 2
3 T34S R21W	Texas Oil and Gas Harper Ranch B # 1
11 T35S R42W	Cities Service Horton C # 3

ever, would probably show that they contain abundant organic material and remains making them an ideal source rock (Reading, 1978).

The shallow seas in the study area would have restricted circulation because of an irregular bottom topography. A warm climate and high nutrient supply from the land could cause high organic productivity in the water (Hallam, 1981). This productivity level could deplete the water of oxygen causing anoxic conditions which would in turn prevent benthic life from destroying the accumulating organic debris. Arthur (1979) suggested that stratification of water and anoxia could also be induced by substantial, low salinity fresh water run off which could form a surface layer "lid" over denser saline water below. The deposition of black shales often is associated with the early stages of transgressions. As the area being inundated widens, freer circulation ensues which would give rise to aerated bottom waters (Hallam, 1981). Storms or climatic changes in wind patterns also could disrupt the stratification of stagnant water and cause aerated conditions to return.

The black shales present in cores examined in this study are assumed to have been deposited under anoxic marine conditions. Unbioturbated intercalated thin black shales and sandstones also were deposited under these conditions. Anoxic conditions may have been very local in extent and may have been interrupted numerous times by oxic events.

Conclusions

During early Morrowan time, the southern portion of the study area was transgressed by a shallow warm epeiric sea. The dominant depositional environment present at this time was shallow marine with most of the sandstone deposition related to storms. The sea regressed during middle Morrowan time and was followed by the development of fluvial and deltaic systems over the entire study area. The rivers were of the meandering type and the deltas were fluvial dominated. The deposition of black shales and the absence of barrier bars or tidal sand ridges suggest that tide and wave activity were of minimal importance. The black shales were deposited under anoxic marine condition and are potential source beds for hydrocarbons.

CHAPTER 7

CONCLUSIONS

1) The sandstones examined in this study are quartz rich with minor to moderate amounts of feldspar and rock fragments. They were largely derived from erosion of older sedimentary units in the craton interior. These sands probably were released by the extensive period of erosion and karst development that took place at the end of the late Mississippian Period. Abundance of authigenic carbonate cement in several samples may cause misinterpretation of lithologies from well log analysis.

2) Volcanic rock fragment bearing and associated sandstones have a larger amount of plagioclase than the other samples studied. They are found in two stratigraphic horizons in Morton County and probably were derived from a few major eruptions of volcanoes in the Ouachita-Marathon orogenic highland.

3) Determining the top of the Chester in southwestern Kansas has been very subjective. Workers in the eastern part of the study area use a top that is substantially above the top chosen by those who work the western part of the basin. Paleontology studies would be the only way to accurately pick this horizon. Since the Morrow and Chester are genetically similar and difficult to distinguish between in the subsurface, they should be treated as one unit, the Morrow-Chester Formation.

4) The top of the Morrow structure and top of St. Genevieve structure maps have similar trends with the shallowest elevations to the north and west, except in Morton County where three semi-parallel fault systems are delineated. These faults may be associated with the Keyes Dome and probably had recurrent movement throughout the Paleozoic.

5) The Morrow-Chester isopach map shows a general thickening of the unit to the west and south with local thickening related to solution features or minor faults. Portions of the fault systems in Morton County were active during Morrowan time as evidenced by a local thickening of the unit. Both the Chester East and Chester West pinch out lines are similar in location and neither is evident in thickness trends on the Morrow-Chester isopach map.

6) Morrowan strata were deposited in a humid, warm climate on a slowly subsiding cratonic shelf. Lower Morrowan depositional environments were dominantly marine, upper Morrow sandstones were deposited in meandering fluvial systems and fluvial dominated deltaic systems. Black shales were deposited in anoxic marine environments which resulted from restricted circulation, oxygen depletion and stratification of the water column. They may be an important source bed for hydrocarbons.

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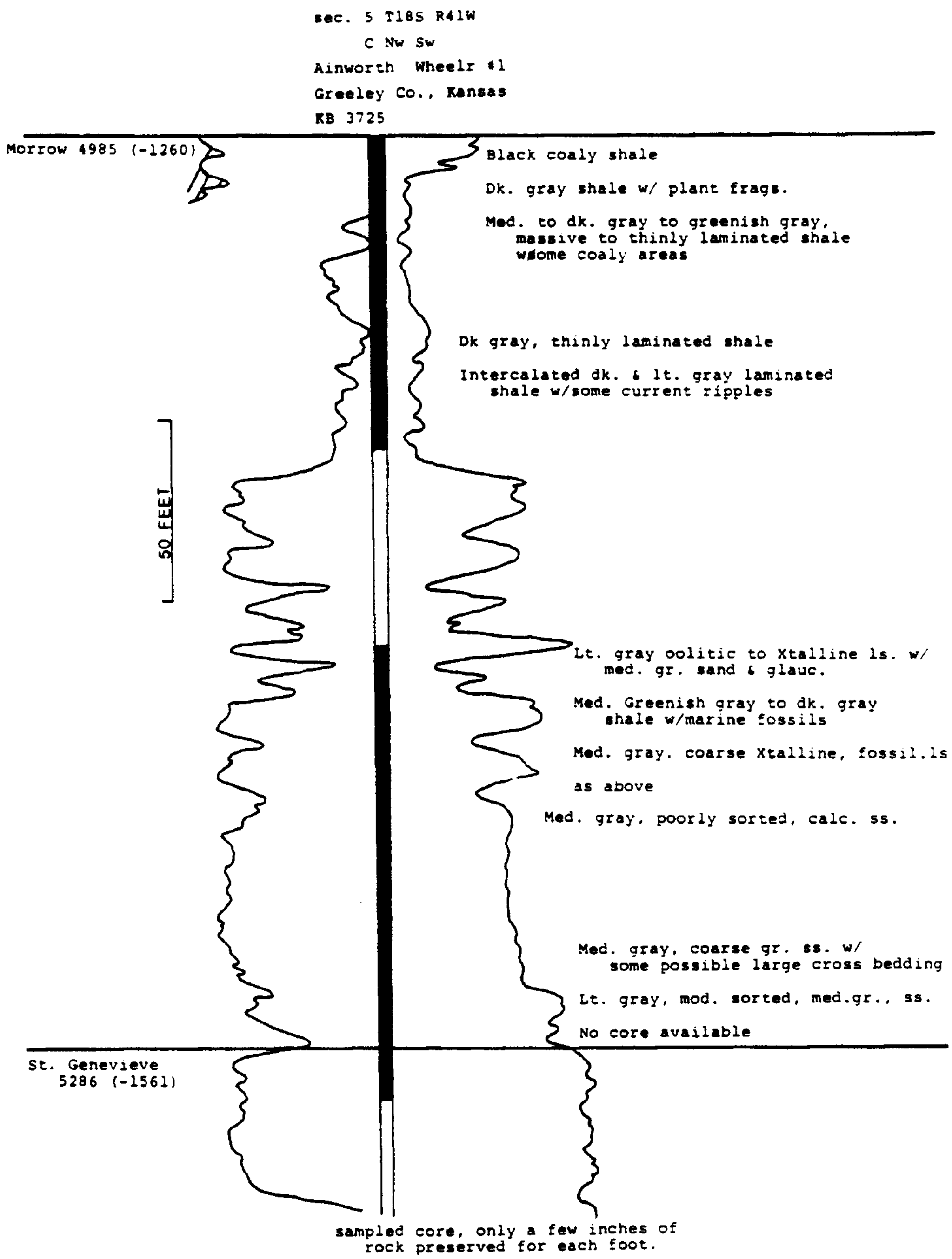
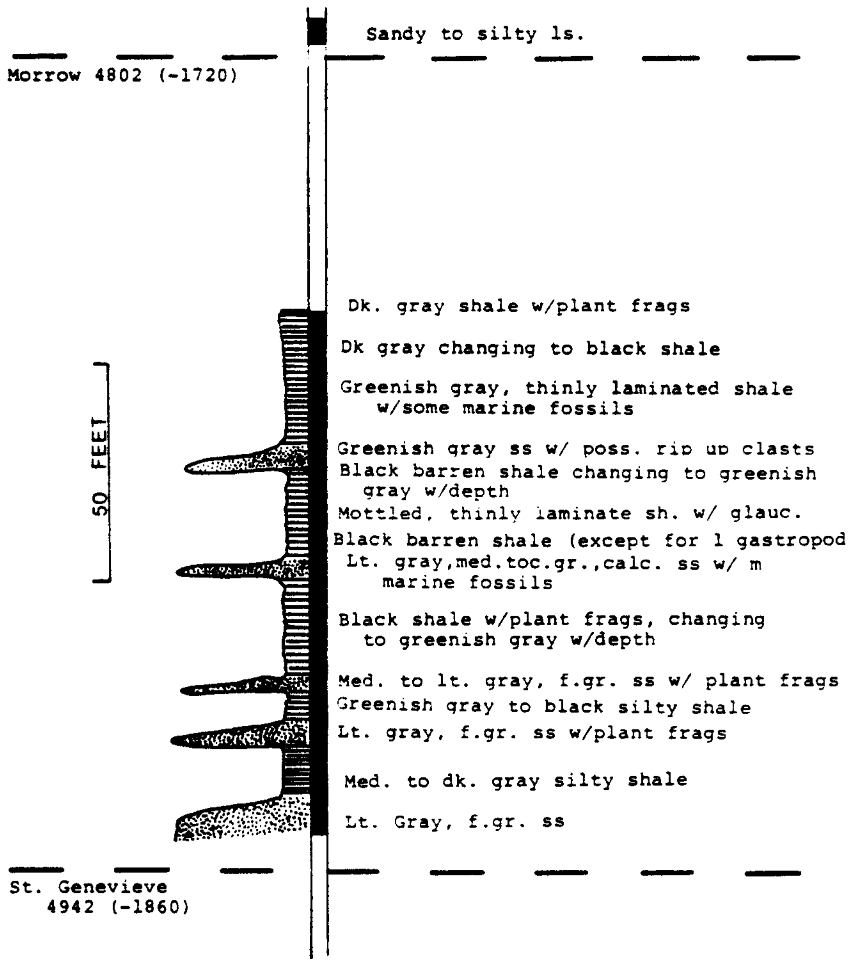
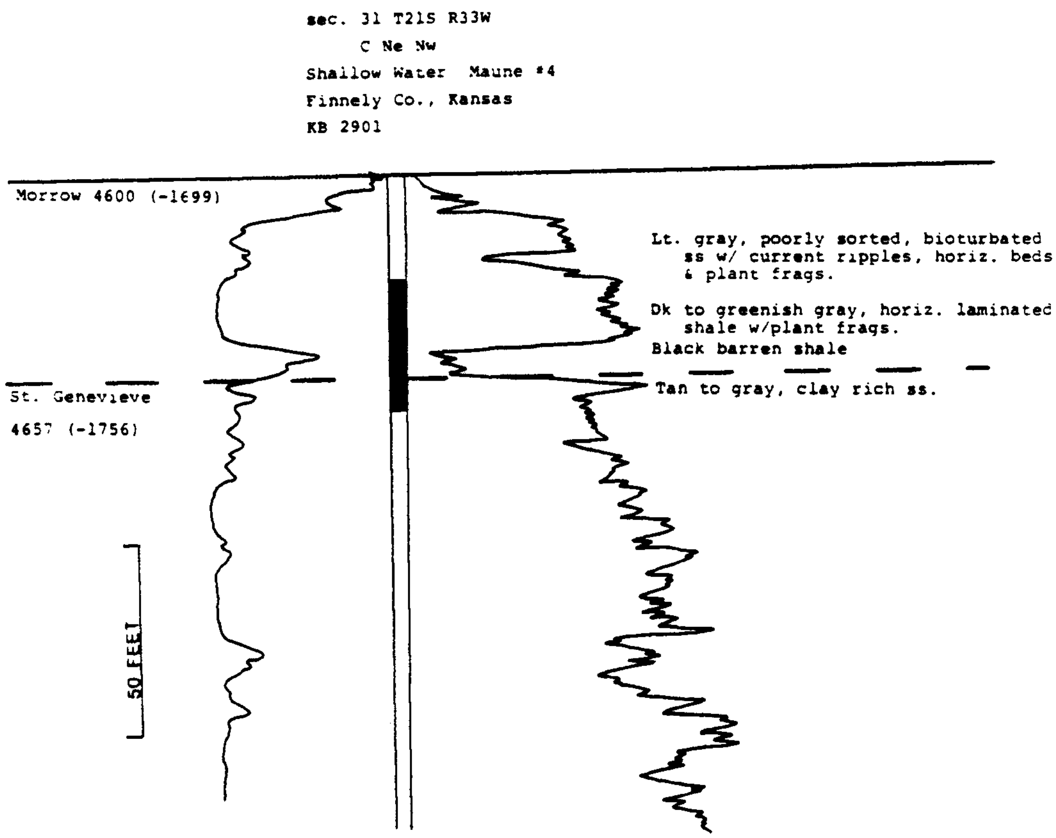
APPENDIX

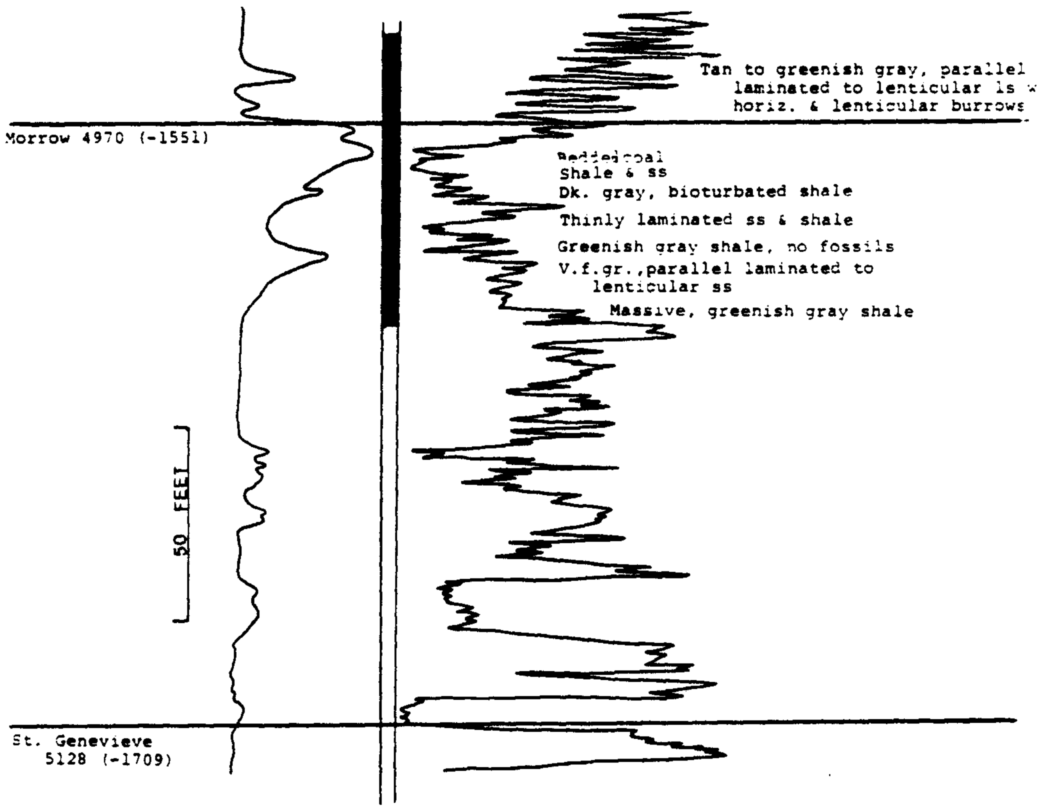

sec. 5 T18S R41W
C Nw Sw
Ainworth Wheelr #1
Greeley Co., Kansas
KB 3725
Morrow 4985 (-1260)
Black coaly shale
Dk. gray shale w/ plant frags.
Med. to dk. gray to greenish gray, massive to thinly laminated shale w/some coaly areas
Dk gray, thinly laminated shale
Intercalated dk. & lt. gray laminated shale w/some current ripples
50 FEET
Lt. gray oolitic to Xtalline ls. w/ med. gr. sand & glauc.
Med. Greenish gray to dk. gray shale w/marine fossils
Med. gray. coarse Xtalline, fossil.ls.
as above
Med. gray, poorly sorted, calc. ss.
Med. gray, coarse gr. ss. w/ some possible large cross bedding
Lt. gray, mod. sorted, med.gr., ss.
No core available
St. Genevieve 5286 (-1561)
sampled core, only a few inches of rock preserved for each foot.

sec. 36 T19S R35W
C Ne Sw
Lauck Oil Lehman #1
Wichita Co., Kansas
KB 3082

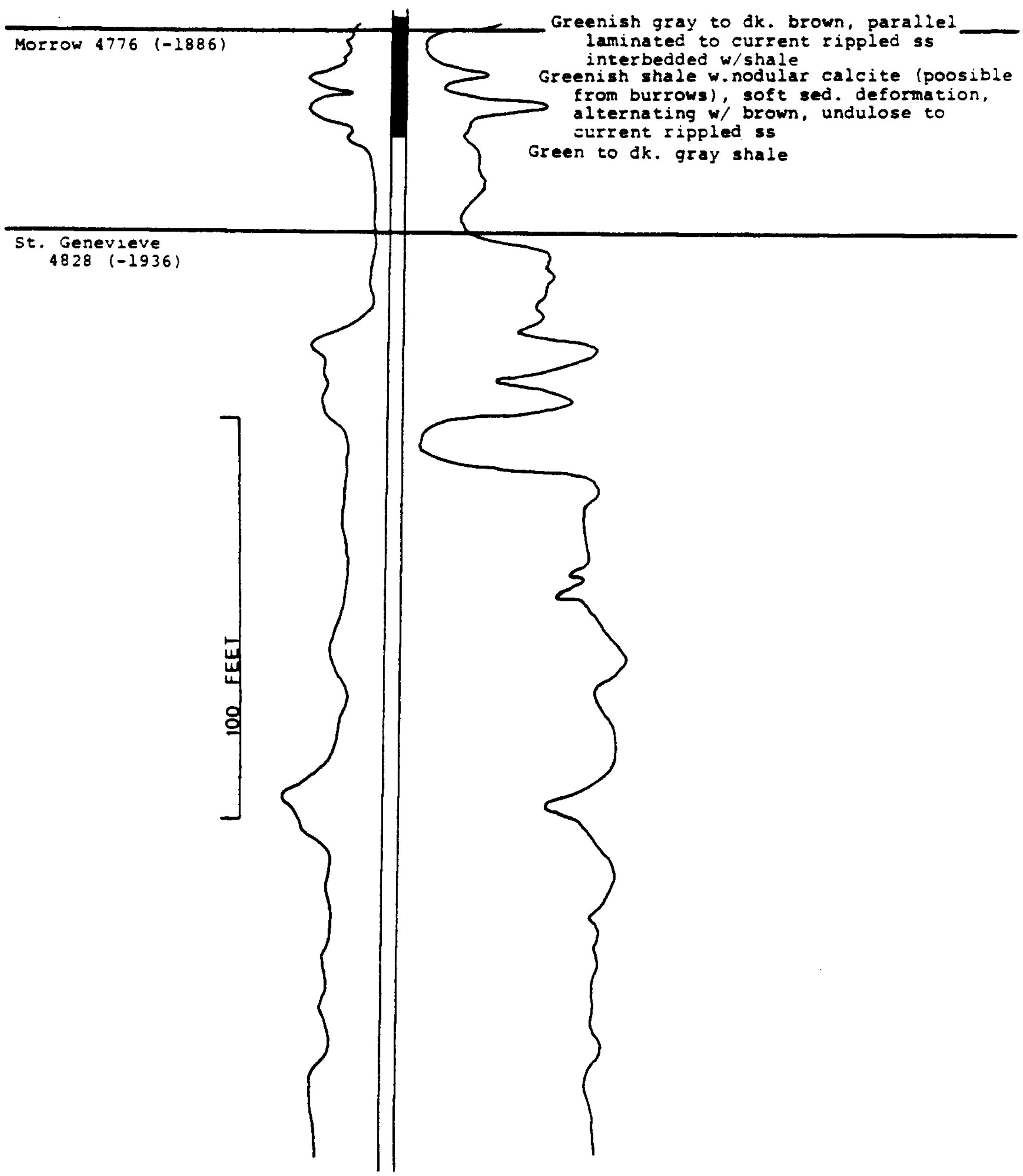


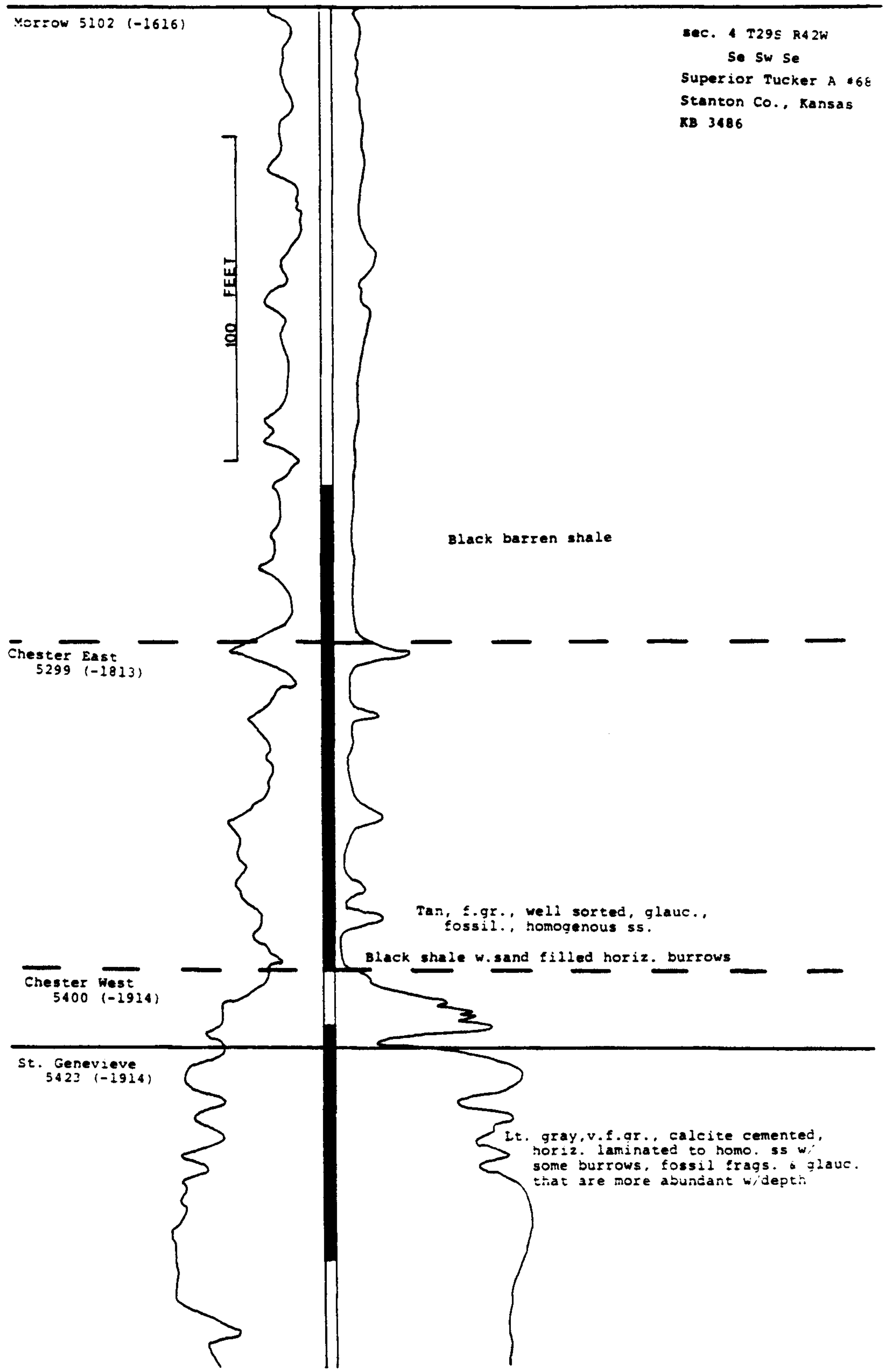

sec. 31 T21S R33W
C Ne Nw
Shallow Water Maune #4
Finnely Co., Kansas
KB 2901
Morrow 4600 (-1699)
St. Genevieve
4657 (-1756)
50 FEET
Lt. gray, poorly sorted, bioturbated ss w/ current ripples, horiz. beds & plant frags.
Dk to greenish gray, horiz. laminated shale w/plant frags.
Black barren shale
Tan to gray, clay rich ss.

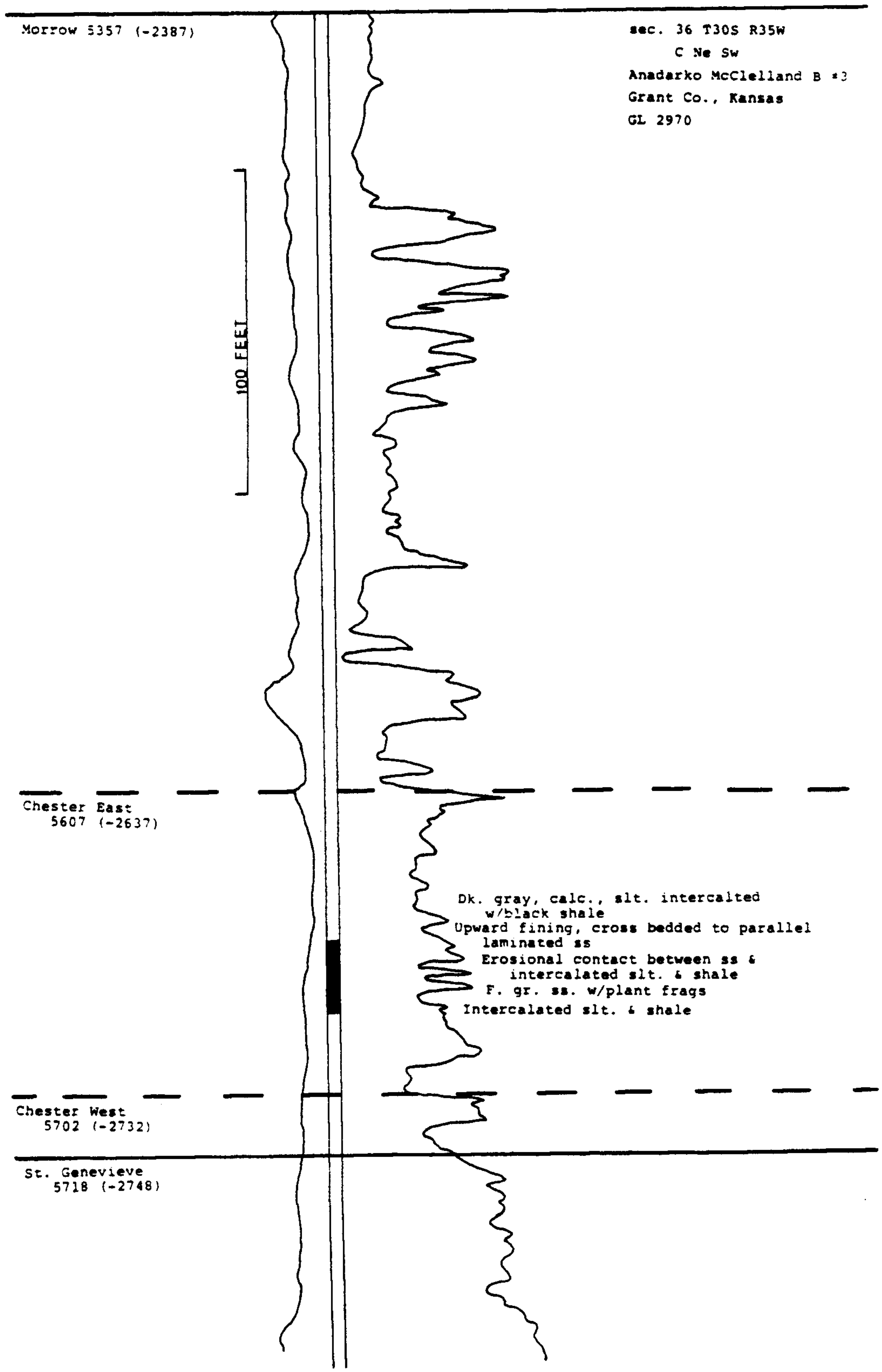
sec. 5 T21S R38W
C Ne Se
Cleary Petroleum Rupp #2
Kearny Co., Kansas
KB 3419

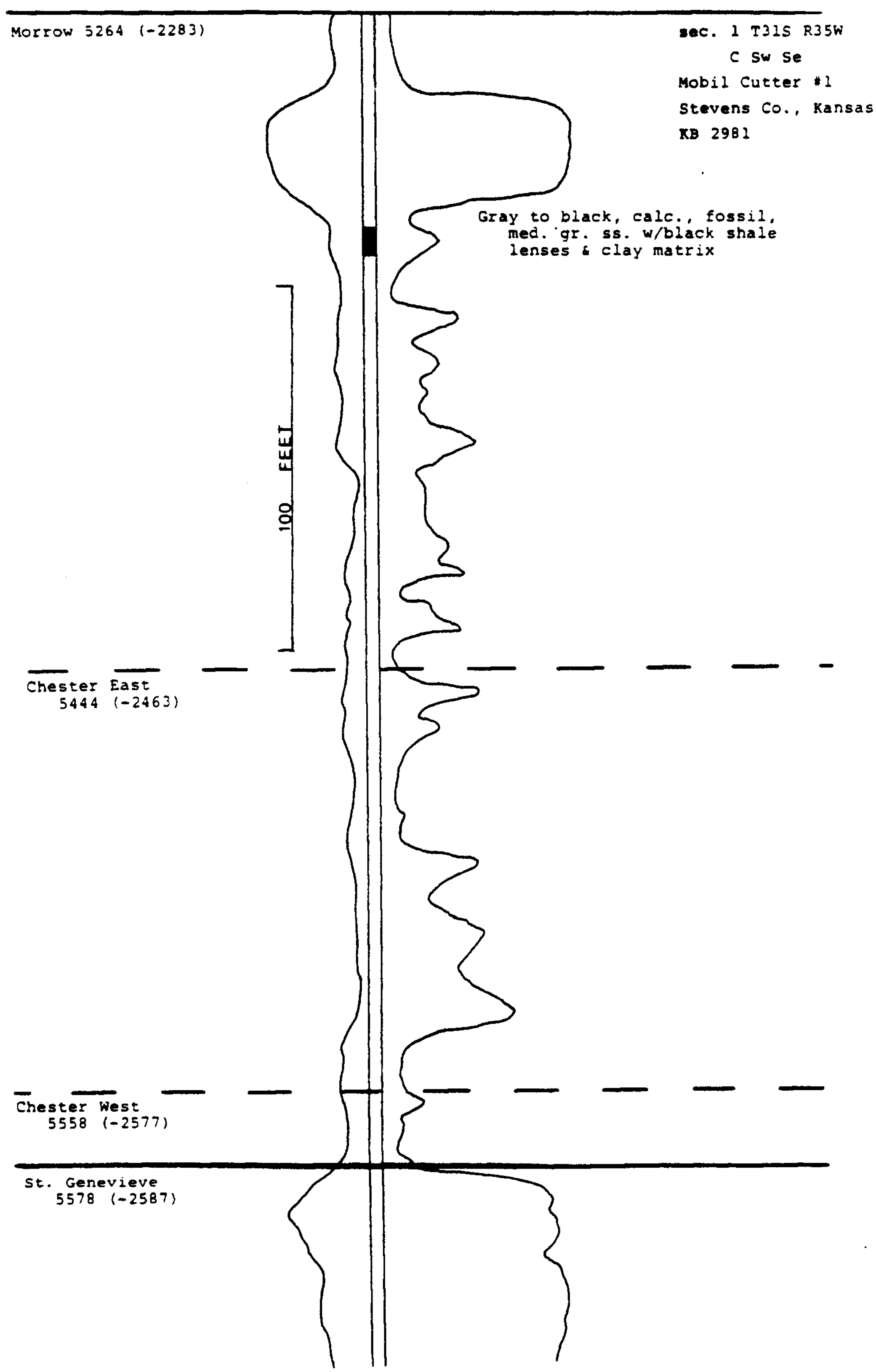


sec. 27 T24S R33W
C Se Ne
Cities Service Tait C #4
Finney Co., Kansas
Kb 2888

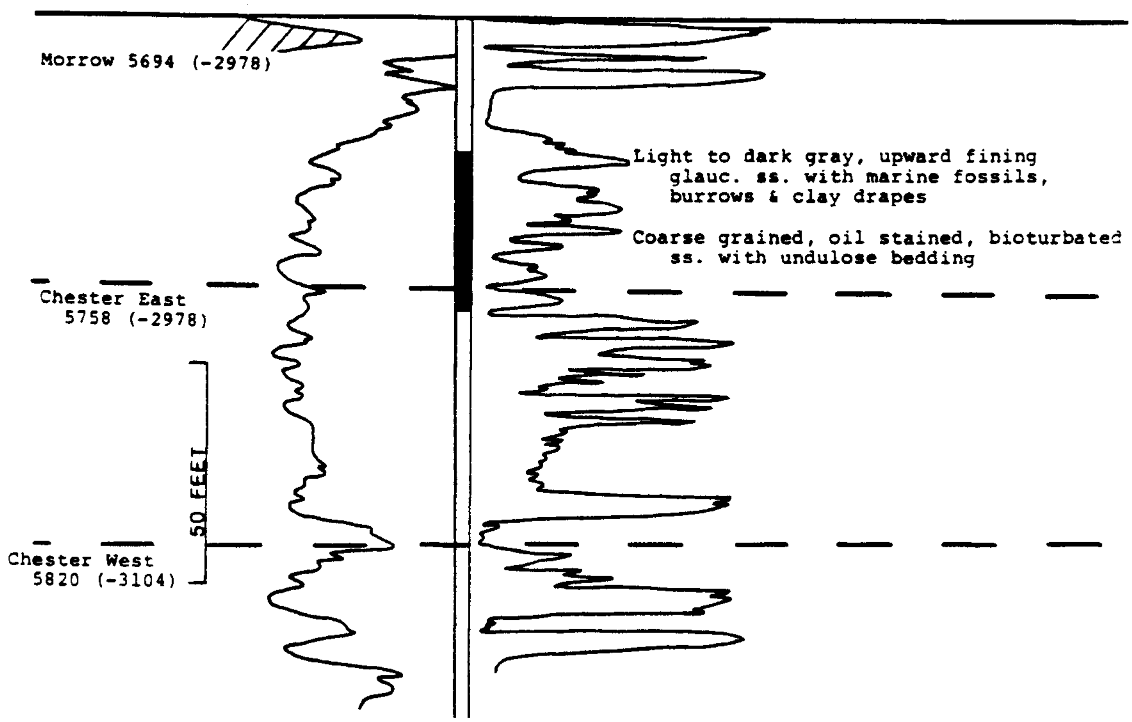


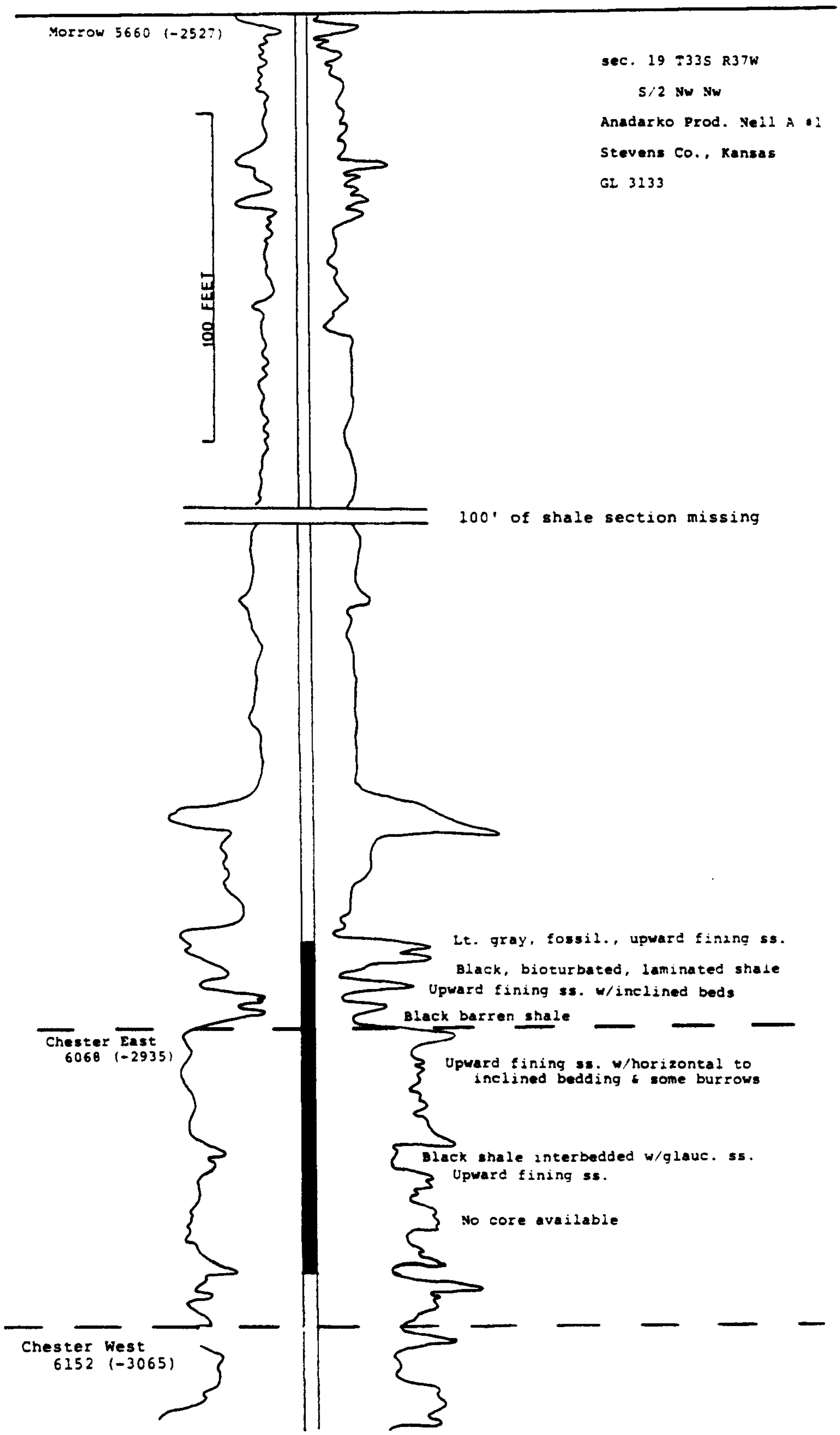

Morrow 5102 (-1616)
sec. 4 T29S R42W
Se Sw Se
Superior Tucker A #68
Stanton Co., Kansas
KB 3486
100 FEET
Black barren shale
Chester East
5299 (-1813)
Tan, f.gr., well sorted, glauc., fossil., homogenous ss.
Black shale w.sand filled horiz. burrows
Chester West
5400 (-1914)
St. Genevieve
5423 (-1914)
Lt. gray, v.f.gr., calcite cemented, horiz. laminated to homo. ss w/ some burrows, fossil frags. & glauc. that are more abundant w/depth

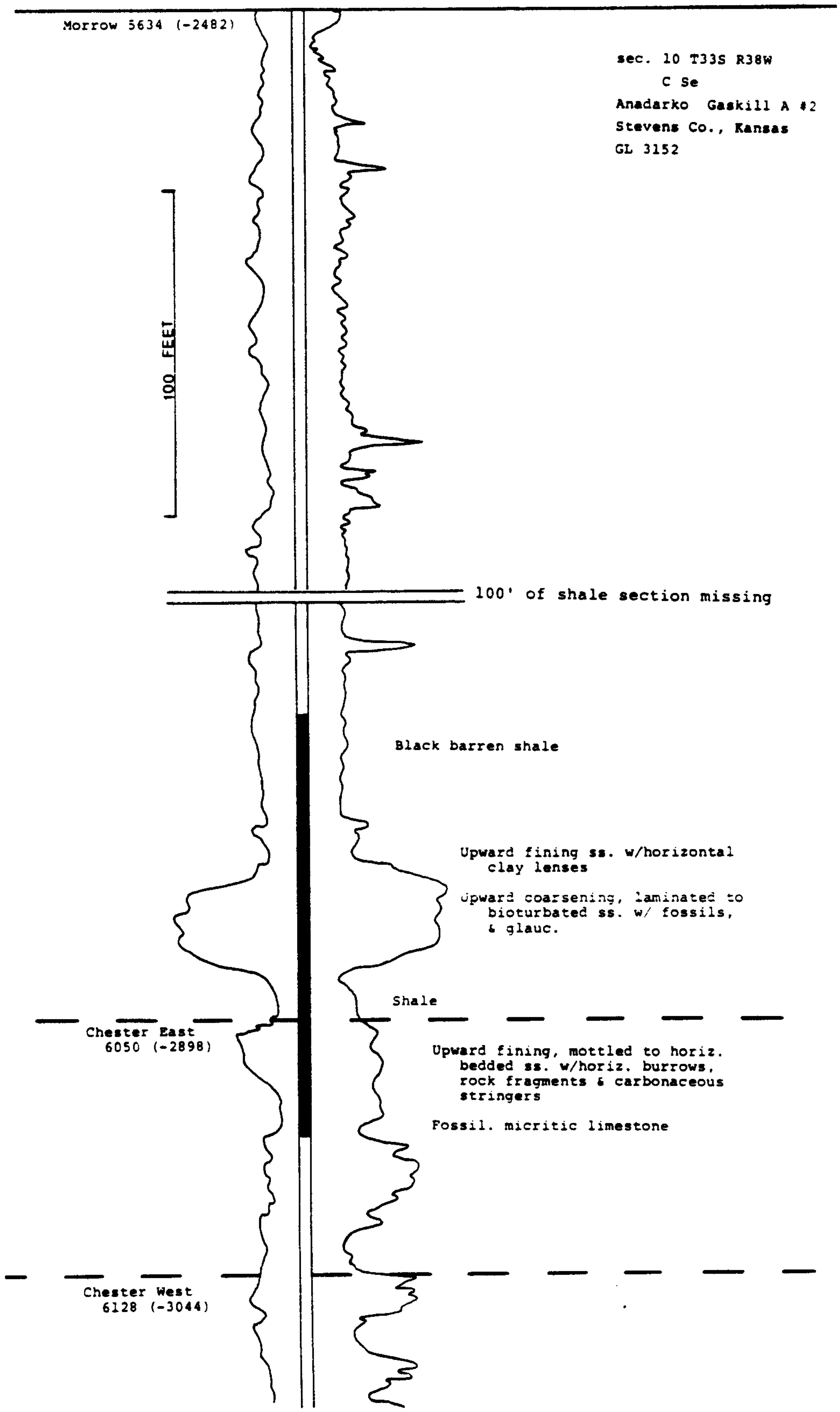

Morrow 5357 (-2387)
sec. 36 T30S R35W
C Ne Sw
Anadarko McClelland B #3
Grant Co., Kansas
GL 2970
100 FEET
Chester East
5607 (-2637)
Dk. gray, calc., slt. intercalted
w/black shale
Upward fining, cross bedded to parallel
laminated ss
Erosional contact between ss &
intercalated slt. & shale
F. gr. ss. w/plant frags
Intercalated slt. & shale
Chester West
5702 (-2732)
St. Genevieve
5718 (-2748)


Morrow 5264 (-2283)
sec. 1 T31S R35W
C Sw Se
Mobil Cutter #1
Stevens Co., Kansas
KB 2981
Gray to black, calc., fossil, med. gr. ss. w/black shale lenses & clay matrix
100 FEET
Chester East 5444 (-2463)
Chester West 5558 (-2577)
St. Genevieve 5578 (-2587)

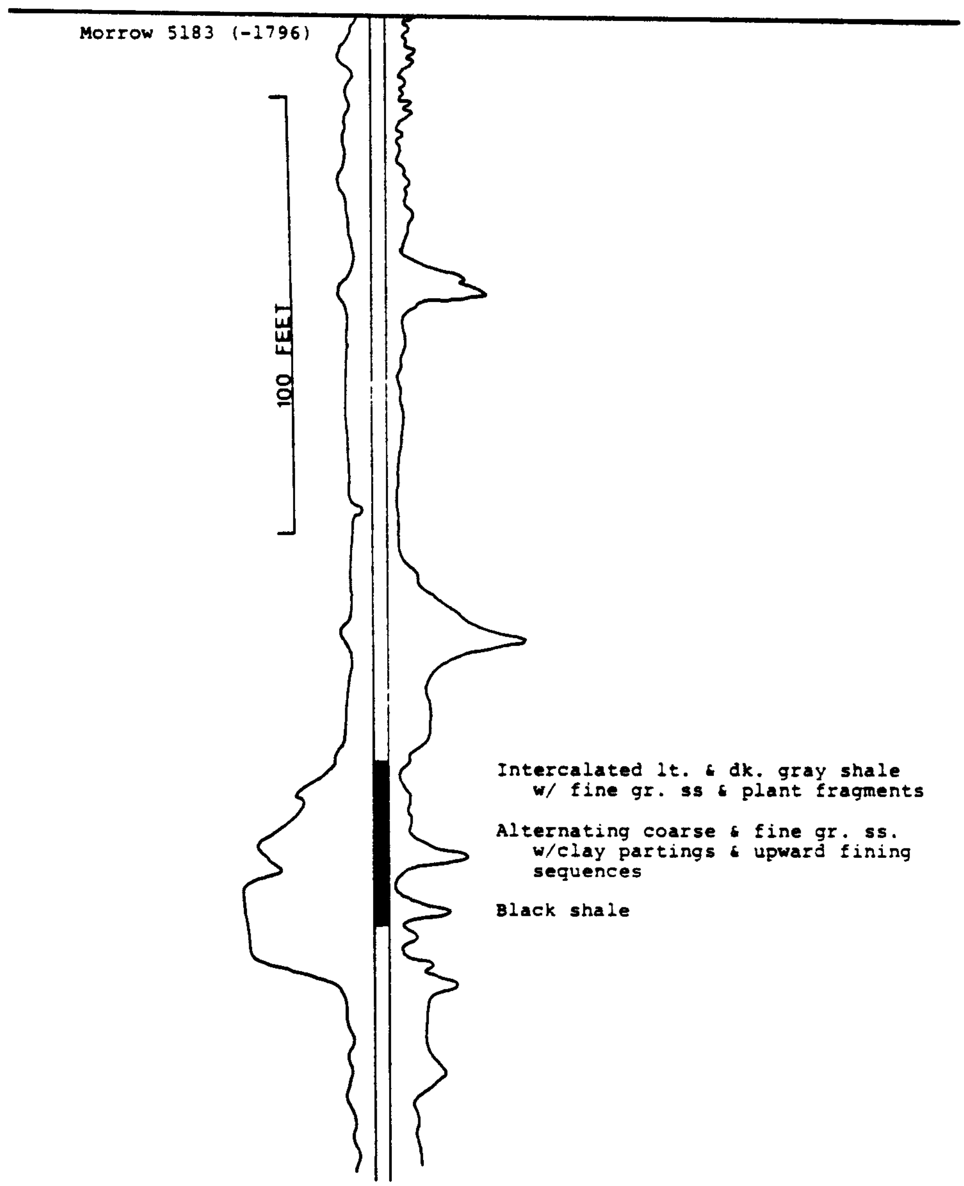
sec. 6 T33S R29W
C Nw Se
Imperial Oil Bolan #1
Meade Co., Kansas
KB 2716

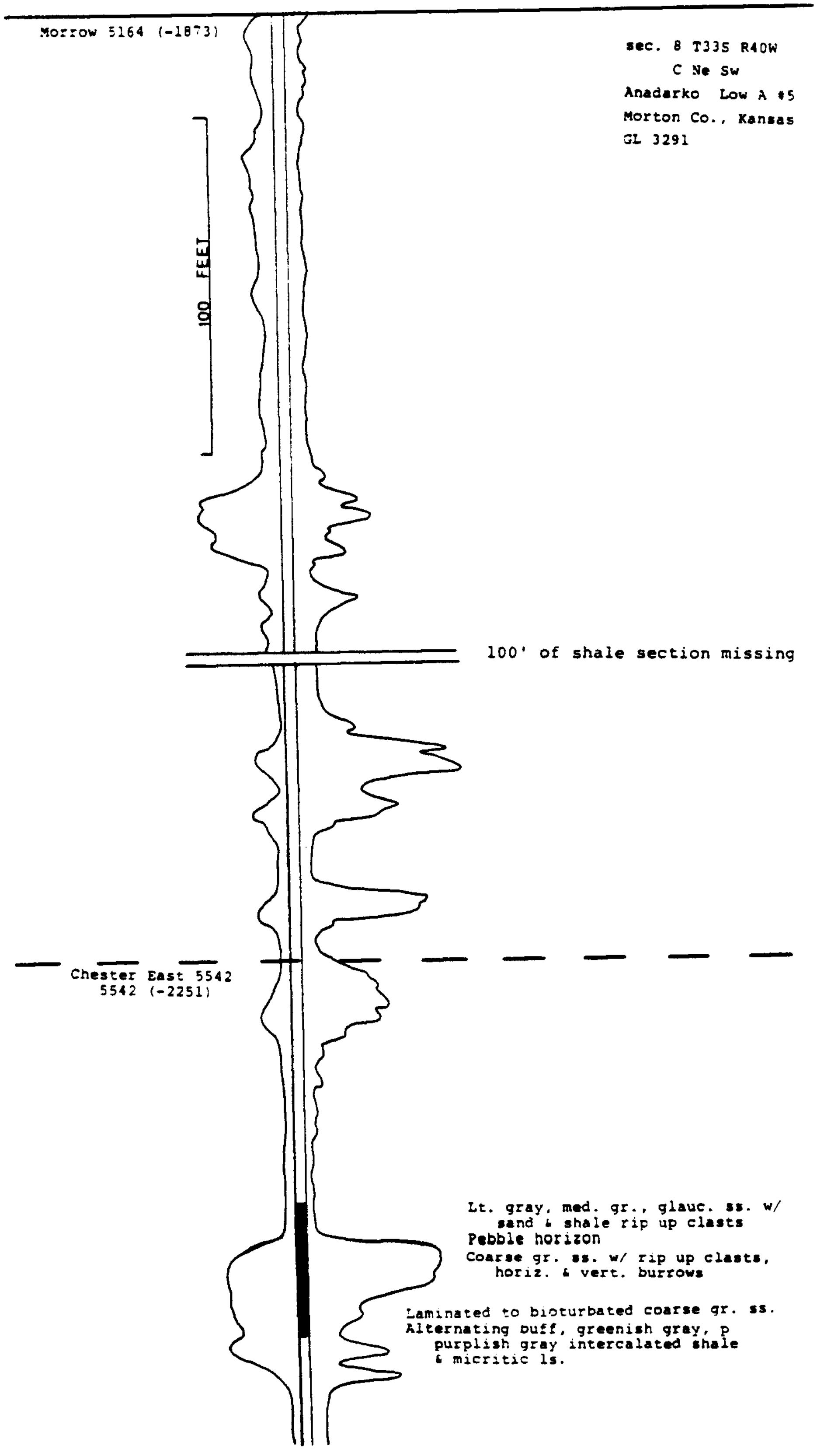



Morrow 5660 (-2527)
sec. 19 T33S R37W
S/2 Nw Nw
Anadarko Prod. Nell A #1
Stevens Co., Kansas
GL 3133
100 FEET
100' of shale section missing
Lt. gray, fossil., upward fining ss.
Black, bioturbated, laminated shale
Upward fining ss. w/inclined beds
Black barren shale
Chester East
6068 (-2935)
Upward fining ss. w/horizontal to
inclined bedding & some burrows
Black shale interbedded w/glauc. ss.
Upward fining ss.
No core available
Chester West
6152 (-3065)

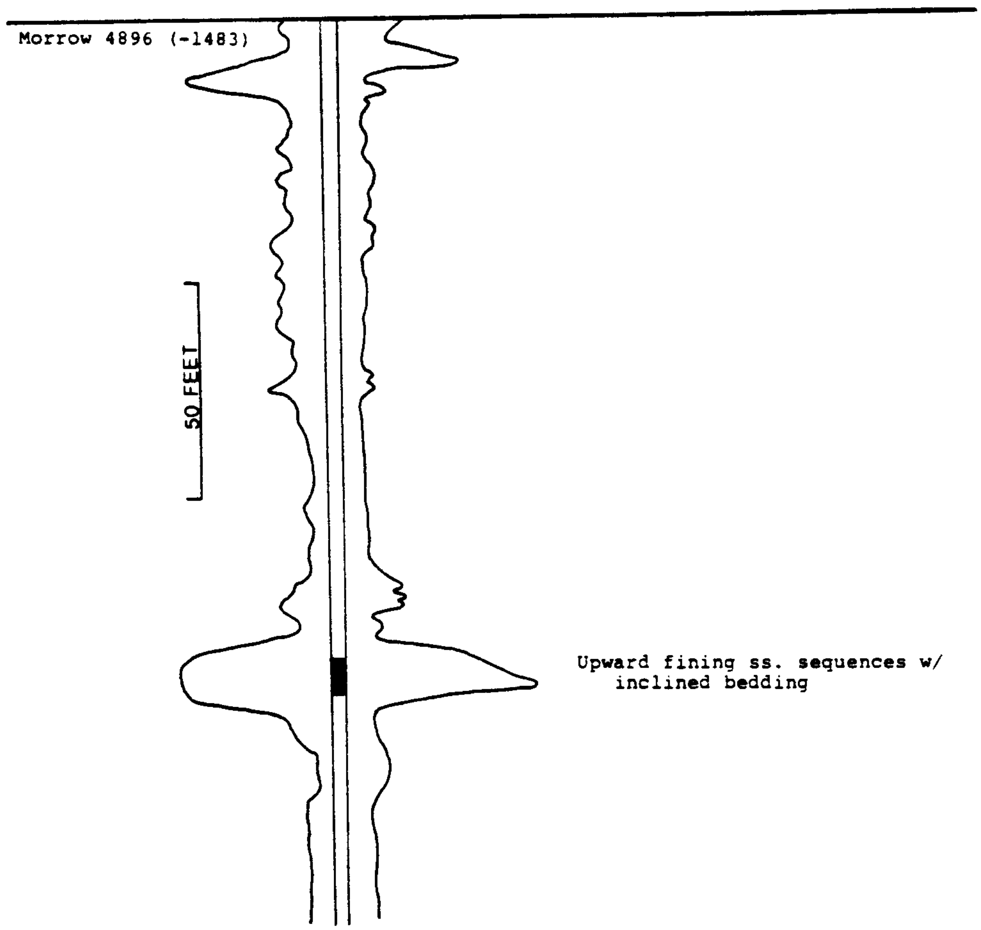

Morrow 5634 (-2482)
sec. 10 T33S R38W
C Se
Anadarko Gaskill A #2
Stevens Co., Kansas
GL 3152
100 FEET
100' of shale section missing
Black barren shale
Upward fining ss. w/horizontal clay lenses
Upward coarsening, laminated to bioturbated ss. w/ fossils, & glauc.
Shale
Chester East
6050 (-2898)
Upward fining, mottled to horiz. bedded ss. w/horiz. burrows, rock fragments & carbonaceous stringers
Fossil. micritic limestone
Chester West
6128 (-3044)

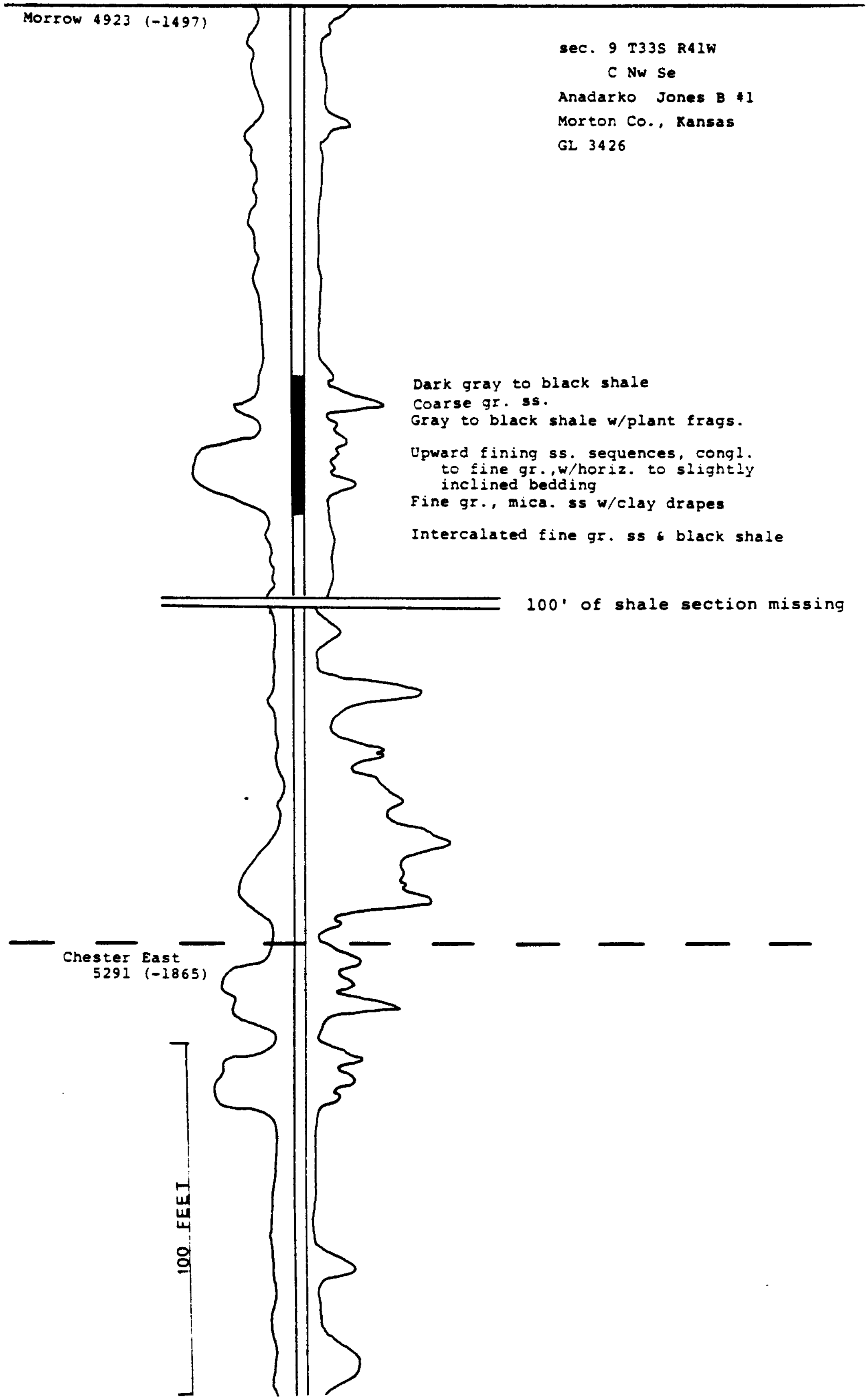
sec. 6 T33S R40W
C Se Nw
Anadarko Low G #1
Morton Co., Kansas
KB 3387




Morrow 5164 (-1873)
sec. 8 T33S R40W
C Ne Sw
Anadarko Low A #5
Morton Co., Kansas
GL 3291
100 FEET
100' of shale section missing
Chester East 5542
5542 (-2251)
Lt. gray, med. gr., glauc. ss. w/ sand & shale rip up clasts
Pebble horizon
Coarse gr. ss. w/ rip up clasts, horiz. & vert. burrows
Laminated to bioturbated coarse gr. ss.
Alternating buff, greenish gray, p purplish gray intercalated shale & micritic ls.

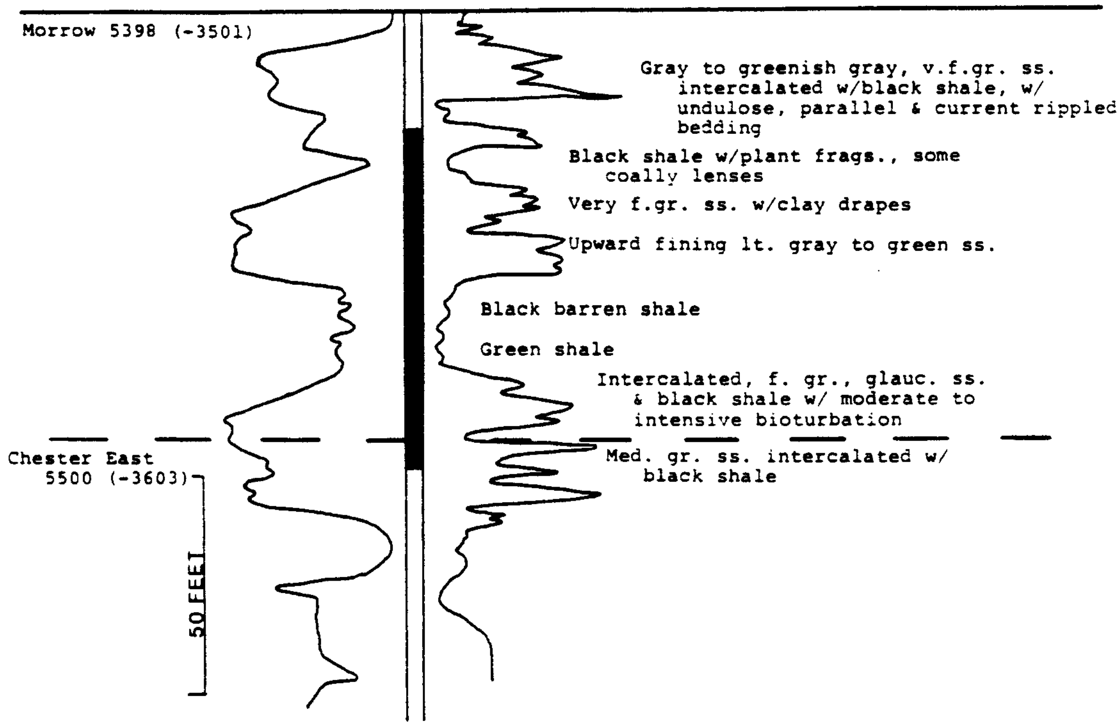
sec. 4 T33S R41W
C Se Se
Cities Service Heyen B #1
Morton Co., Kansas
KB 3413

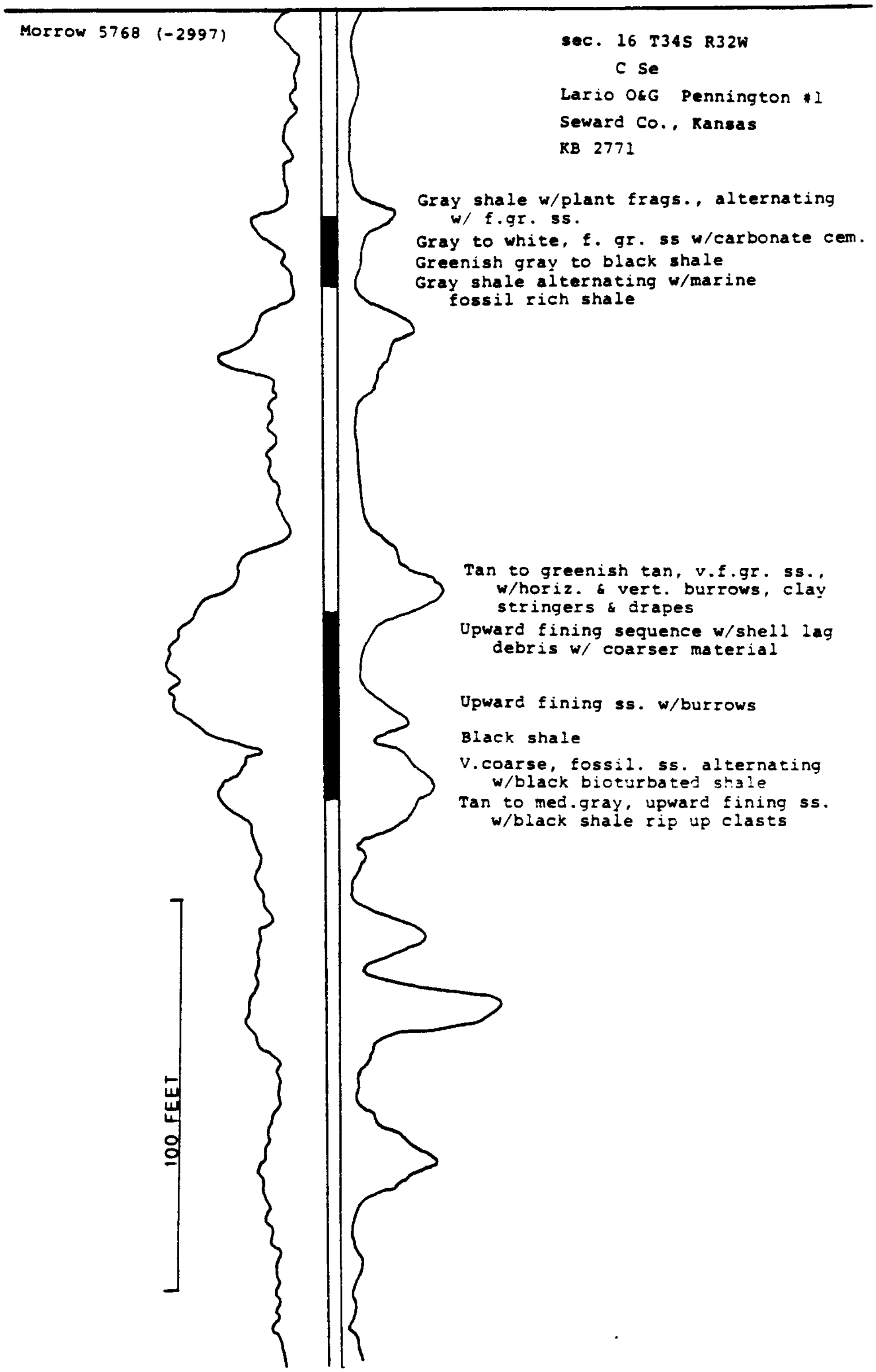


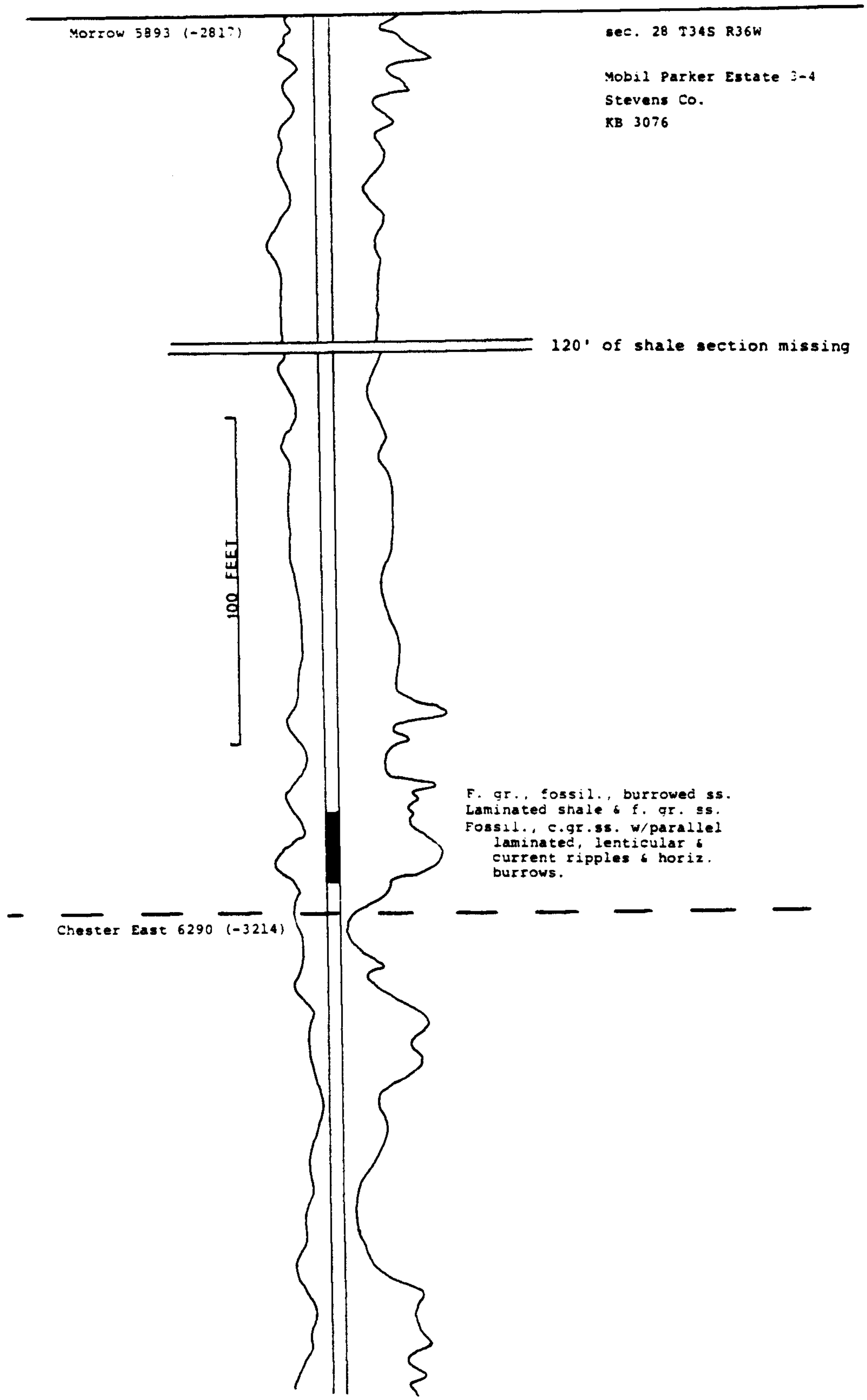


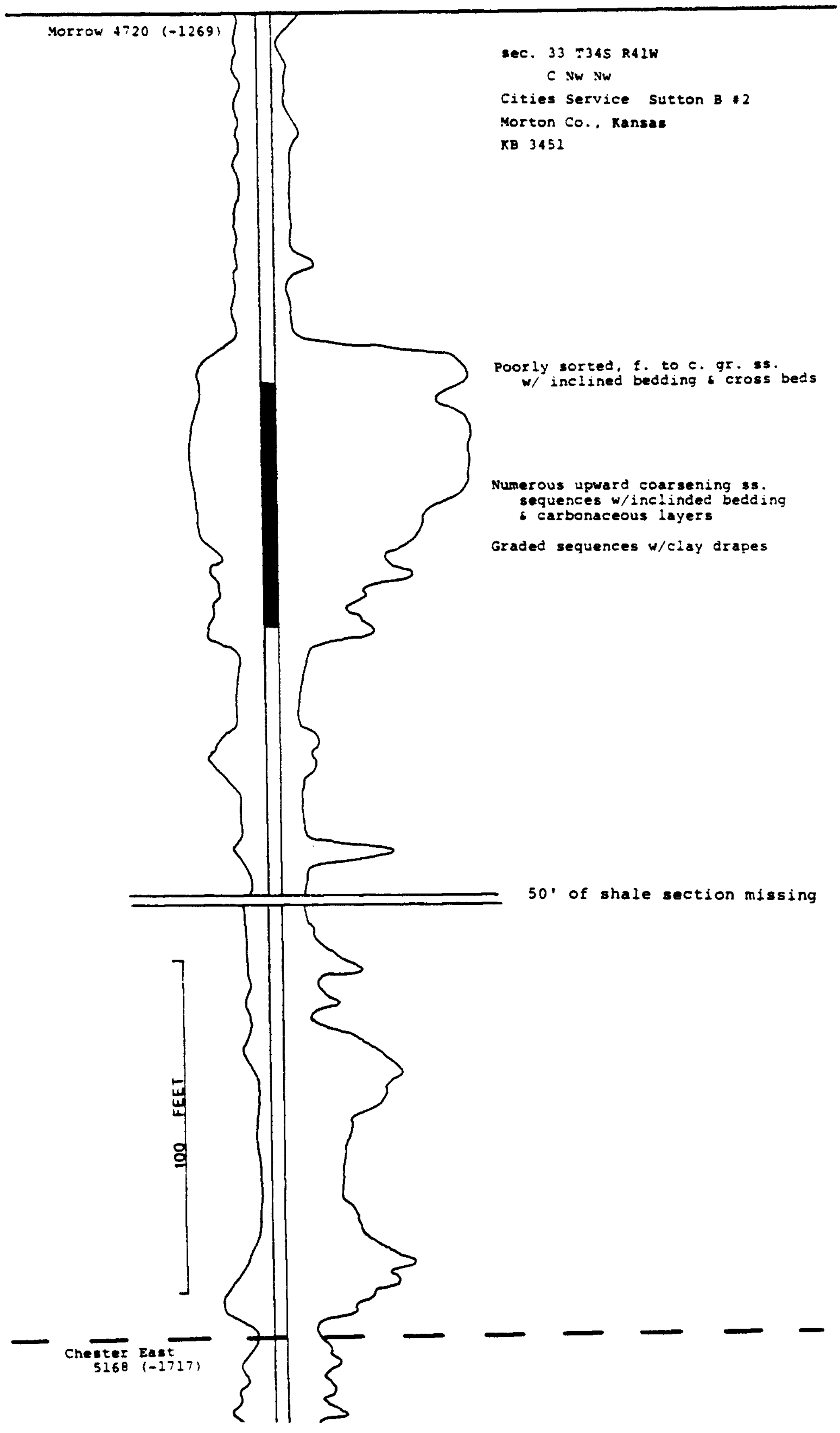
Morrow 4923 (-1497)
sec. 9 T33S R41W
C Nw Se
Anadarko Jones B #1
Morton Co., Kansas
GL 3426
Dark gray to black shale
Coarse gr. ss.
Gray to black shale w/plant frags.
Upward fining ss. sequences, congl. to fine gr.,w/horiz. to slightly inclined bedding
Fine gr., mica. ss w/clay drapes
Intercalated fine gr. ss & black shale
100' of shale section missing
Chester East
5291 (-1865)
100 FEET

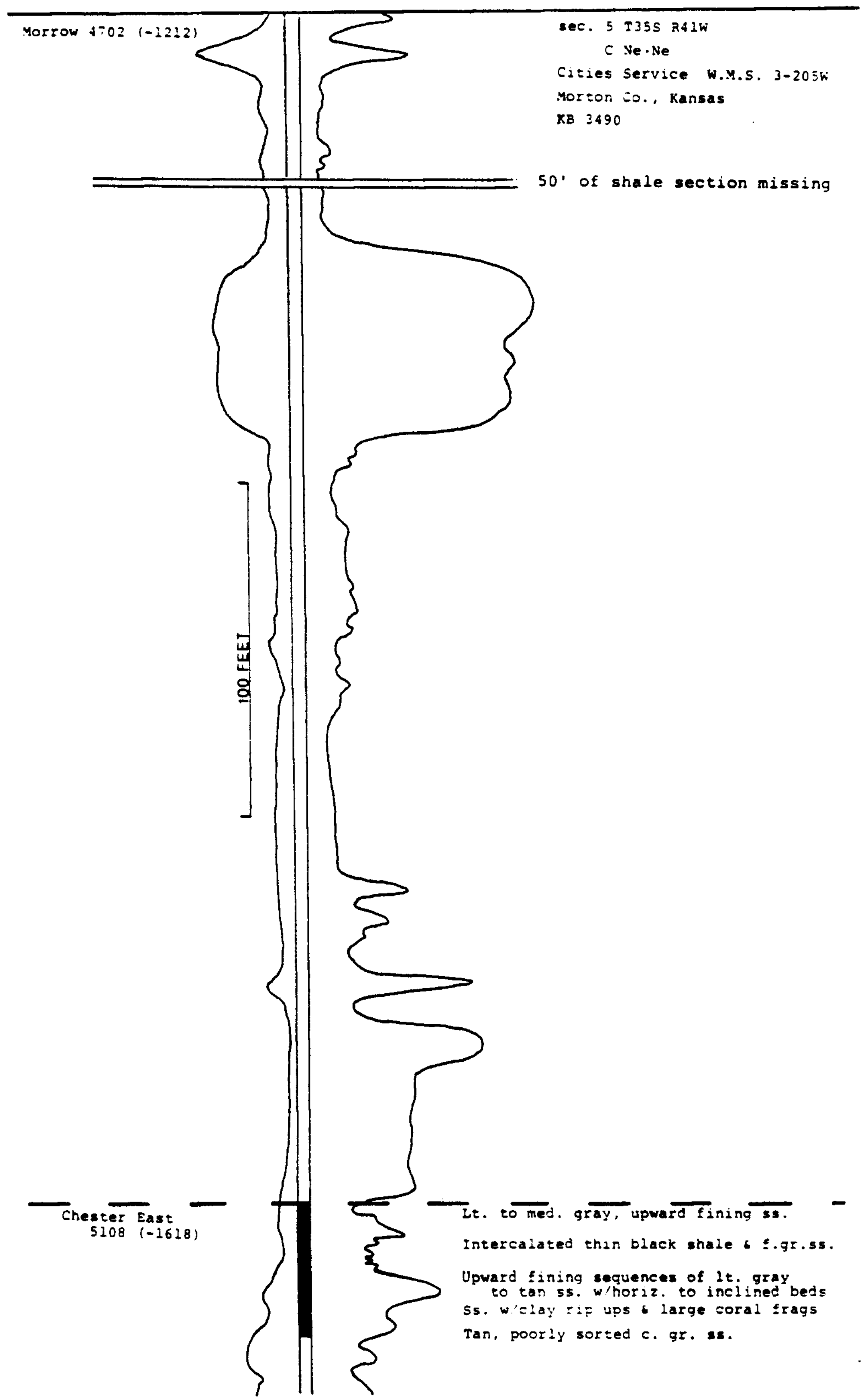
sec. 3 T34S R21W
C Se Ne
Texas O & G Harper Ranch B #1
Clark Co., Kansas
KB 1897

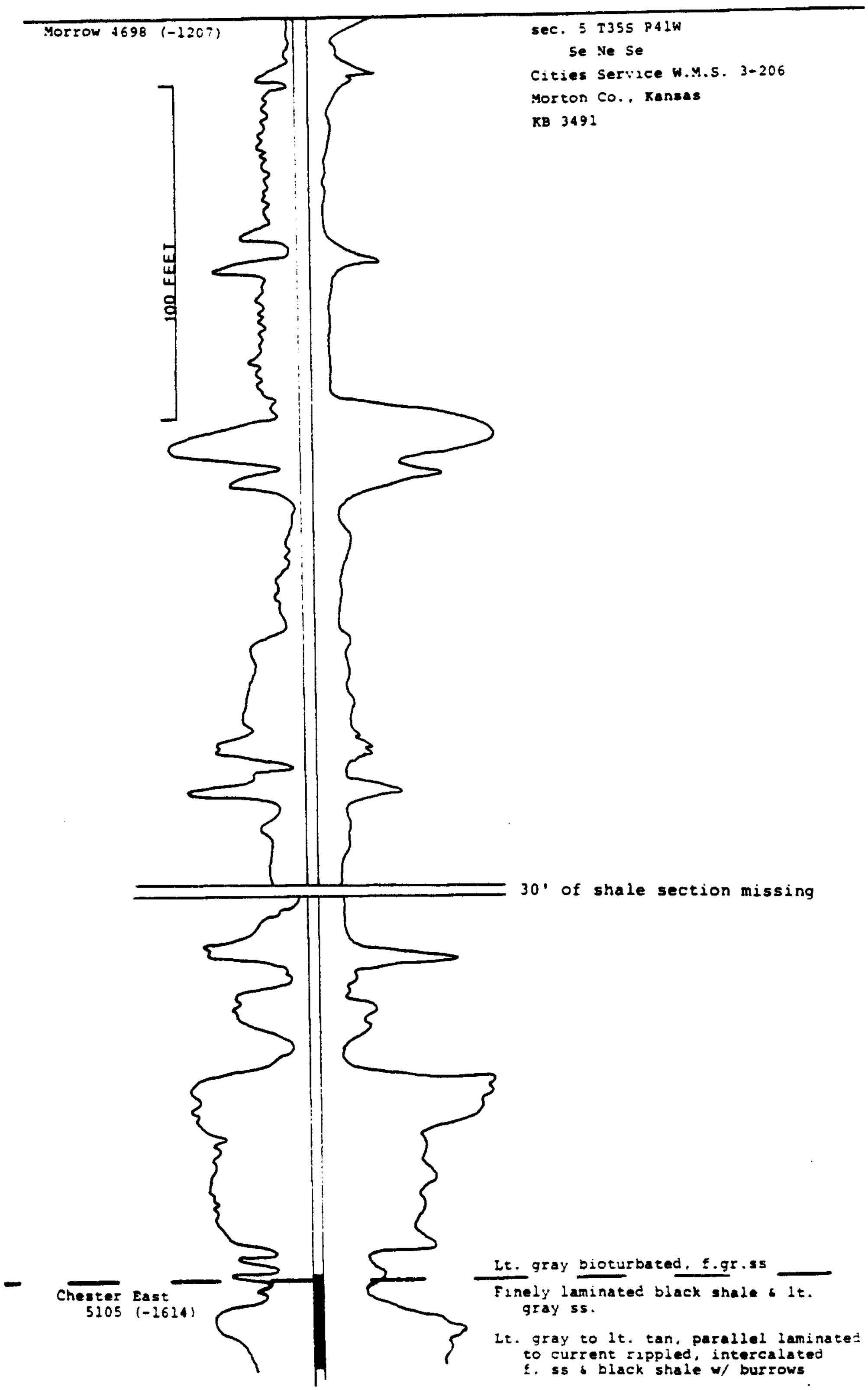


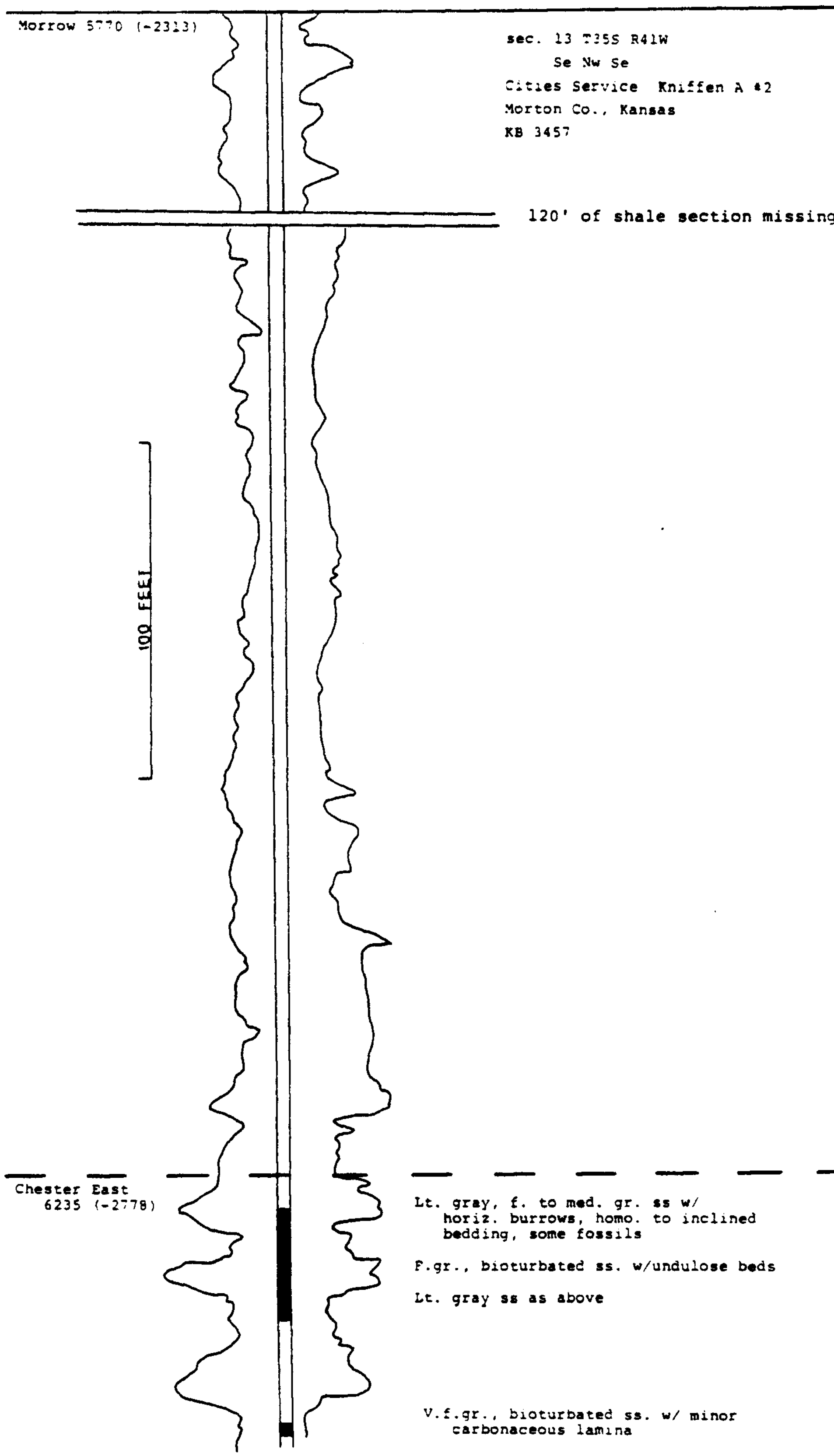

Morrow 5768 (-2997)
sec. 16 T34S R32W
C Se
Lario O&G Pennington #1
Seward Co., Kansas
KB 2771
Gray shale w/plant frags., alternating w/ f.gr. ss.
Gray to white, f. gr. ss w/carbonate cem.
Greenish gray to black shale
Gray shale alternating w/marine fossil rich shale
Tan to greenish tan, v.f.gr. ss., w/horiz. & vert. burrows, clay stringers & drapes
Upward fining sequence w/shell lag debris w/ coarser material
Upward fining ss. w/burrows
Black shale
V.coarse, fossil. ss. alternating w/black bioturbated shale
Tan to med.gray, upward fining ss. w/black shale rip up clasts
100 FEET


Morrow 5893 (-2817)
sec. 28 T34S R36W
Mobil Parker Estate 3-4
Stevens Co.
KB 3076
120' of shale section missing
100 FEET
F. gr., fossil., burrowed ss.
Laminated shale & f. gr. ss.
Fossil., c.gr.ss. w/parallel laminated, lenticular & current ripples & horiz. burrows.
Chester East 6290 (-3214)

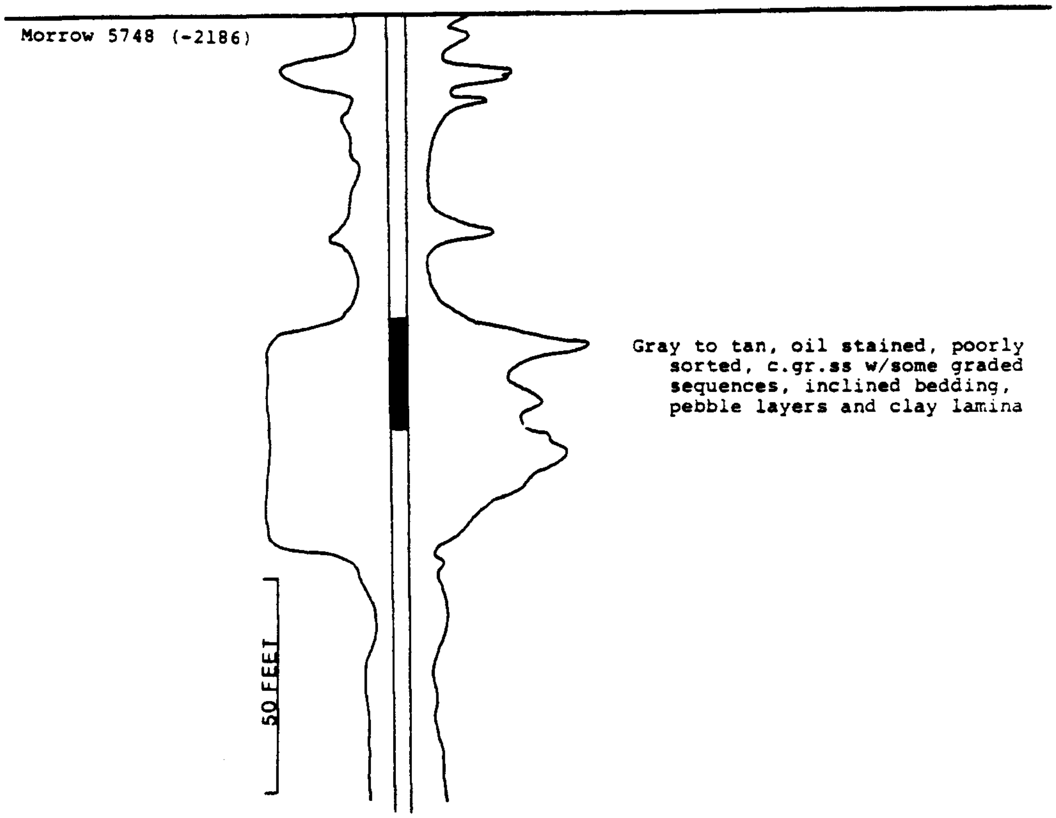

Morrow 4720 (-1269)
sec. 33 T34S R41W
C Nw Nw
Cities Service Sutton B #2
Morton Co., Kansas
KB 3451
Poorly sorted, f. to c. gr. ss.
w/ inclined bedding & cross beds
Numerous upward coarsening ss.
sequences w/inclinded bedding
& carbonaceous layers
Graded sequences w/clay drapes
50' of shale section missing
100 FEET
Chester East
5168 (-1717)

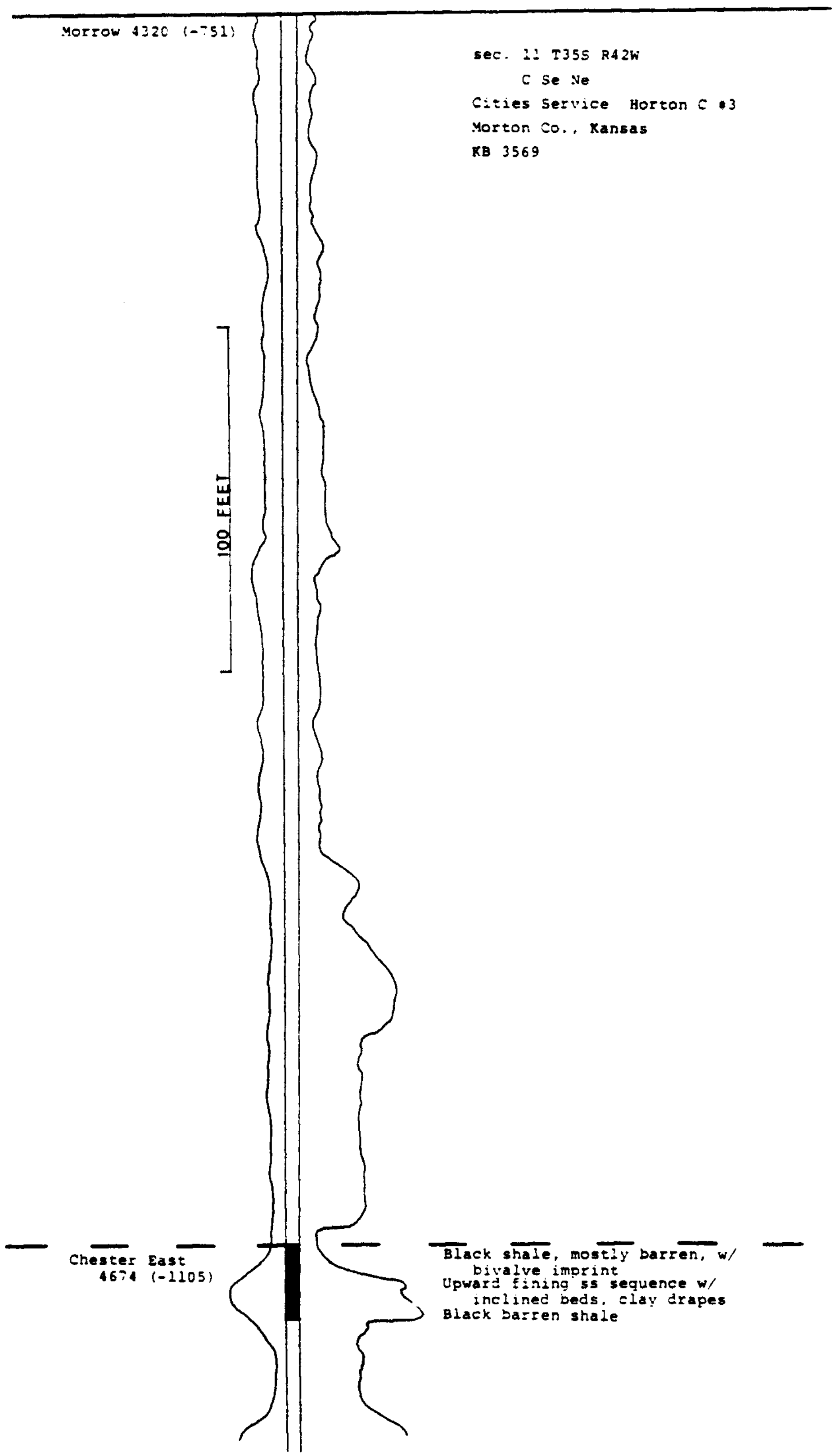

Morrow 4702 (-1212)
sec. 5 T35S R41W
C Ne·Ne
Cities Service W.M.S. 3-205W
Morton Co., Kansas
KB 3490
50' of shale section missing
100 FEET
Chester East
5108 (-1618)
Lt. to med. gray, upward fining ss.
Intercalated thin black shale & f.gr.ss.
Upward fining sequences of lt. gray
to tan ss. w/horiz. to inclined beds
Ss. w/clay rip ups & large coral frags
Tan, poorly sorted c. gr. ss.


Morrow 4698 (-1207)
sec. 5 T35S R41W
Se Ne Se
Cities Service W.M.S. 3-206
Morton Co., Kansas
KB 3491
100 FEET
30' of shale section missing
Lt. gray bioturbated, f.gr.ss
Chester East
5105 (-1614)
Finely laminated black shale & lt. gray ss.
Lt. gray to lt. tan, parallel laminated to current rippled, intercalated f. ss & black shale w/ burrows


Morrow 5770 (-2313)
sec. 13 T35S R41W
Se Nw Se
Cities Service Kniffen A #2
Morton Co., Kansas
KB 3457
120' of shale section missing
100 FEET
Chester East
6235 (-2778)
Lt. gray, f. to med. gr. ss w/ horiz. burrows, homo. to inclined bedding, some fossils
F.gr., bioturbated ss. w/undulose beds
Lt. gray ss as above
V.f.gr., bioturbated ss. w/ minor carbonaceous lamina

sec. 18 T35S R41W
C Sw Se
Cities Service Daniels C #1
Morton Co., Kansas
KB 3562




Morrow 4320 (-751)
sec. 11 T35S R42W
C Se Ne
Cities Service Horton C #3
Morton Co., Kansas
KB 3569
100 FEET
Chester East
4674 (-1105)
Black shale, mostly barren, w/ bivalve imprint
Upward fining ss sequence w/ inclined beds, clay drapes
Black barren shale