SEQUENCE STRATIGRAPHY OF THE LOWER MIDDLE PENNSYLVANIAN AND DISTRIBUTION OF SELECTED SANDSTONES, EASTERN HUGOTON EMBAYMENT, SOUTHWESTERN KANSAS

by

John C. Youle

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John C. Youle
B.A., Miami University, 1979

Submitted to the Department of Geology and the Faculty of the Graduate School of the University of Kansas in partial fulfillment of the requirements for the degree of Master of Science.

Professor in Charge

Committee Members

For the Department

10/15/92
Date thesis accepted

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This work is dedicated to Brigid Eadie Youle who displayed remarkable restraint in waiting until twelve hours after my defense to be born and to her patient and loving mother.

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ABSTRACT

Sequence-stratigraphic methodology reveals the depositional history and stratal architecture of the onlapping succession of lower Middle Pennsylvanian strata from Seward County, Kansas, onto the Central Kansas uplift. Sequence boundaries, identified in core by evidence of subaerial exposure upon subtidal rocks, are correlated to wireline logs and traced throughout the eastern Hugoton embayment. Thirteen fourth- or fifth-order sequences are recognized from the "V" shale (Desmoinesian) to the top of the Kearny Formation (possible Morrowan age strata) or the unconformity surface beneath the Pennsylvanian. Neutron-density-log cross-sections reveal that sequences are sigmoidal in shape, downlap into the basin, to the southwest, and toplap onto the shelf, to the northeast.

A continuous core from the Pendleton Land & Exploration #1 Schauf (16-27s-29w, Gray County) includes a section of strata correlative with the "Thirteen Finger lime" of Oklahoma (probable Atokan-age strata). This section of core is informally referred to as the "Gray group". The "Gray group" lies disconformably upon the Kearny and is conformable or slightly disconformable (by depositional hiatus) with the overlying Cherokee Group in the eastern Hugoton embayment.

Depositional sequences in the "Gray group" and Cherokee Group have been traced from lower-shelf to proximal-shelf positions. Lower-shelf sequences are 10 to 30 feet thick (3 to 9 m). They consist of a basal black radioactive shale (4 to 10 ft; 1.25 to 3 m thick) that grades upwards into a clean dense limestone (6 to 15 ft; 1.75 to 4.5 m thick). Lower-shelf black shales thin and grade into limestones and less radioactive gray shales in the mid-shelf. Thin lower-shelf limestones thicken (up to 75 ft; 23 m) and grade into bioclastic and phylloidal wackestones and packstones in the mid-shelf. Mid-shelf limestones thin further landward and grade into thin (up to 10 feet; 3 m thick) siliciclastic-dominated units or amalgamated soil profiles.

Reservoir-quality productive sandstones (up to 60 feet; 18 m thick) in the Stewart and Minneola Pools are localized at the updip terminus of lower "Gray group" sequences where they onlap the sub-Pennsylvanian unconformity surface. "Gray group" sandstones were deposited in estuaries developed within paleovalleys incised up to twenty meters into underlying Mississippian carbonates.

CHAPTER ONE

INTRODUCTION

Purpose and Significance

This investigation was undertaken for three reasons; 1) to establish the stratigraphic relationships between undifferentiated rocks of possible Atokan age and those of the underlying Kearny Formation (Morrowan ?) and the overlying Cherokee Group, 2) to define and describe rocks of possible Atokan age in western Kansas and 3) to gain an understanding of the distribution of basal Pennsylvanian reservoir-quality sandstones in the eastern Hugoton embayment of southwestern Kansas.

Stratigraphic relationships between Lower and lower Middle Pennsylvanian units in western Kansas have been controversial since subsurface studies of the area began (Thompson, 1944). Most of the controversy centers around the age and stratigraphic position of oil-productive basal Pennsylvanian sandstones (commonly referred to as "Morrow") and their relationship to overlying carbonates. The carbonate section between the base of the Marmaton Group and the top of locally distributed basal Pennsylvanian sandstones thin from over 100 m in the Hugoton embayment to less than 38 m on the flank of the Central Kansas uplift. Two schools of thought have been developed to explain the thinning of these carbonates. The first school uses dubious and scanty biostratigraphic data to split the carbonates into two units, a basal Atokan-age succession and an overlying Desmoinesian-age succession (e.g. Maher, 1947, etc; Huffman, 1959; Abels, 1959; etc.). Thinning of the carbonates is thought to reflect the offlap of Atokan-age limestones (either by erosion, non-deposition or both) prior to Desmoinesian deposition. The second school of thought lumps the carbonates between the Marmaton Group and basal Pennsylvanian sandstones into one lithostratigraphic unit (e.g. Rascoe, 1962). The second school of thought implies that the basal Pennsylvanian sandstones are lateral equivalents of the carbonates and that a facies transition occurs as the carbonates thin and onlap the sub-Pennsylvanian unconformity surface.

The second problem this investigation seeks to resolve is the distribution pattern of productive basal Pennsylvanian sandstones in the eastern Hugoton embayment. Basal Pennsylvanian sandstones ("Morrow" sandstones of the petroleum industry) have produced almost ten million barrels of oil in the eastern Hugoton embayment. They are localized within paleovalleys that have been incised into pre-Pennsylvanian carbonates (Mannhard and Busch, 1974; Emery and Sutterlin, 1986).

The petroleum industry has long enjoyed success in locating these incised valleys using reflection seismology (Clark, 1987). However, valley-fill sandstones grade laterally into non-reservoir shales and siltstones that cannot be distinguished from sandstones using current geophysical techniques. Further confounding explorationists is the localized distribution of reservoir-quality rock within long axial segments of the incised paleovalleys. The difficulty in locating these reservoirs has resulted in poor success ratios during exploration and development drilling. Consequently, these potentially important reservoirs have become largely avoided by the petroleum industry.

Methods and Area of Investigation

A sequence stratigraphic framework for the lower Middle Pennsylvanian was constructed from wireline-log correlations of sequence boundaries originally identified in core. Sequence boundaries were identified in 26 m of continuous core from a well in Gray County (Pendleton Ld. & Ex., #1 Schauf 16-27S-29W). The core was slabbed, polished and described in detail, and eleven thin sections were prepared including one or more from most of the sequence boundary surfaces. Sequence boundaries are identified by an abrupt basinward shift in facies marked by a well-developed exposure surface upon subtidal or lower shoreface rocks. Regional wireline-log cross-sections were constructed and sequence boundaries were traced from the #1 Schauf over an area of about 14,000 square kilometers including portions of eight counties from Scott and Finney Counties on the north and west to Clark and Ford Counties in the south and east (Figs. 1 & 2).

Sequence stratigraphic methods reveal the spatial configurations of depositional sequences and distribution of facies in lower Middle Pennsylvanian strata from Seward County to positions proximal to the Central Kansas uplift. These methods are also instrumental in dividing basal Pennsylvanian sandstones into temporally distinct units that can be correlated regionally and studied independently from other productive basal Pennsylvanian sandstones. Depositional sequences in the "Gray group" and lower Cherokee Group are informally designated with small case letters *a-m*.

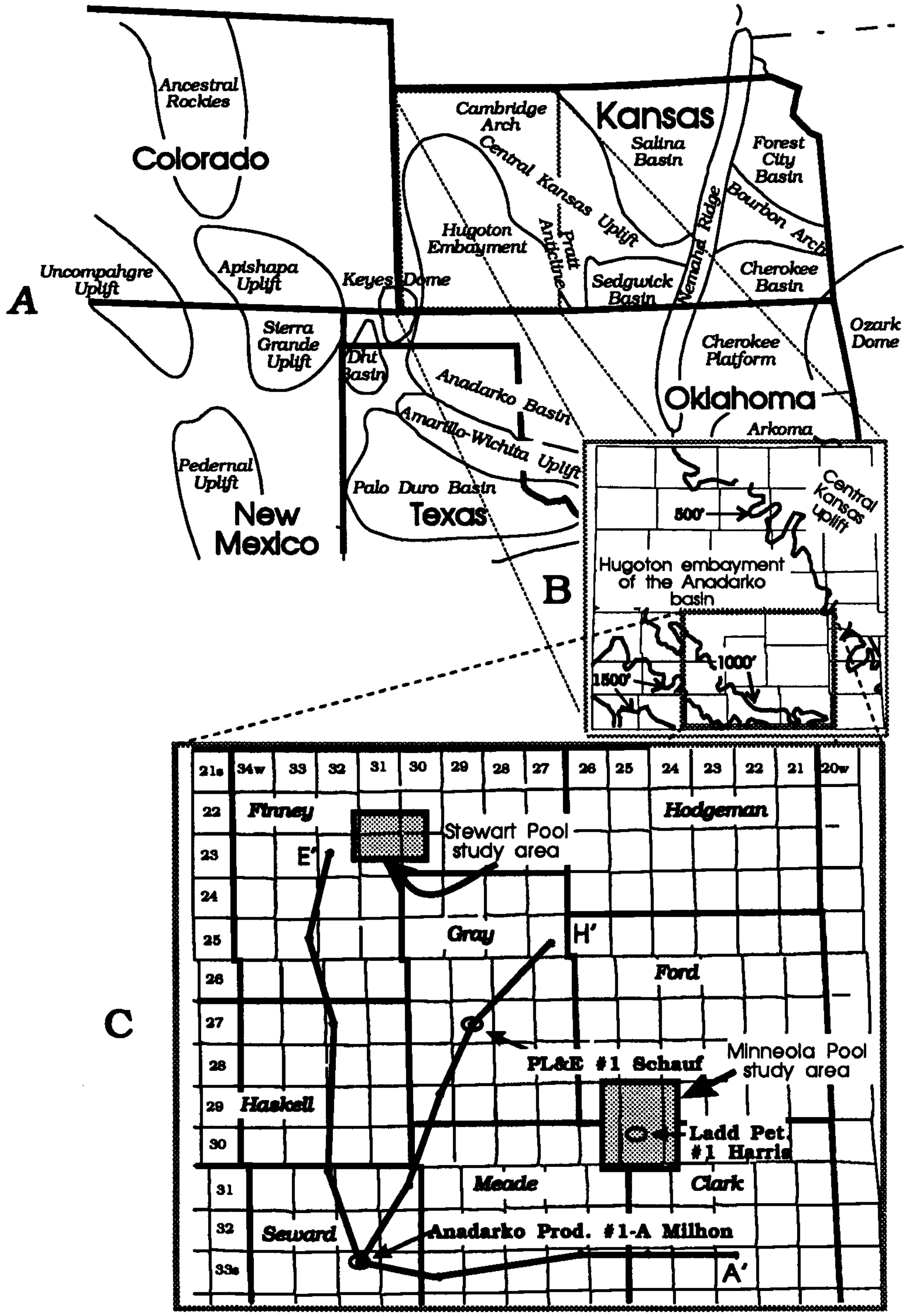

Fig. 1 A. Pennsylvanian features of the Midcontinent (modified from Moore, 1979). B. Isopach of Lansing to Mississippian (500' C.I.; modified from Merriam, 1963). C. Study area including key wells and cross sections.

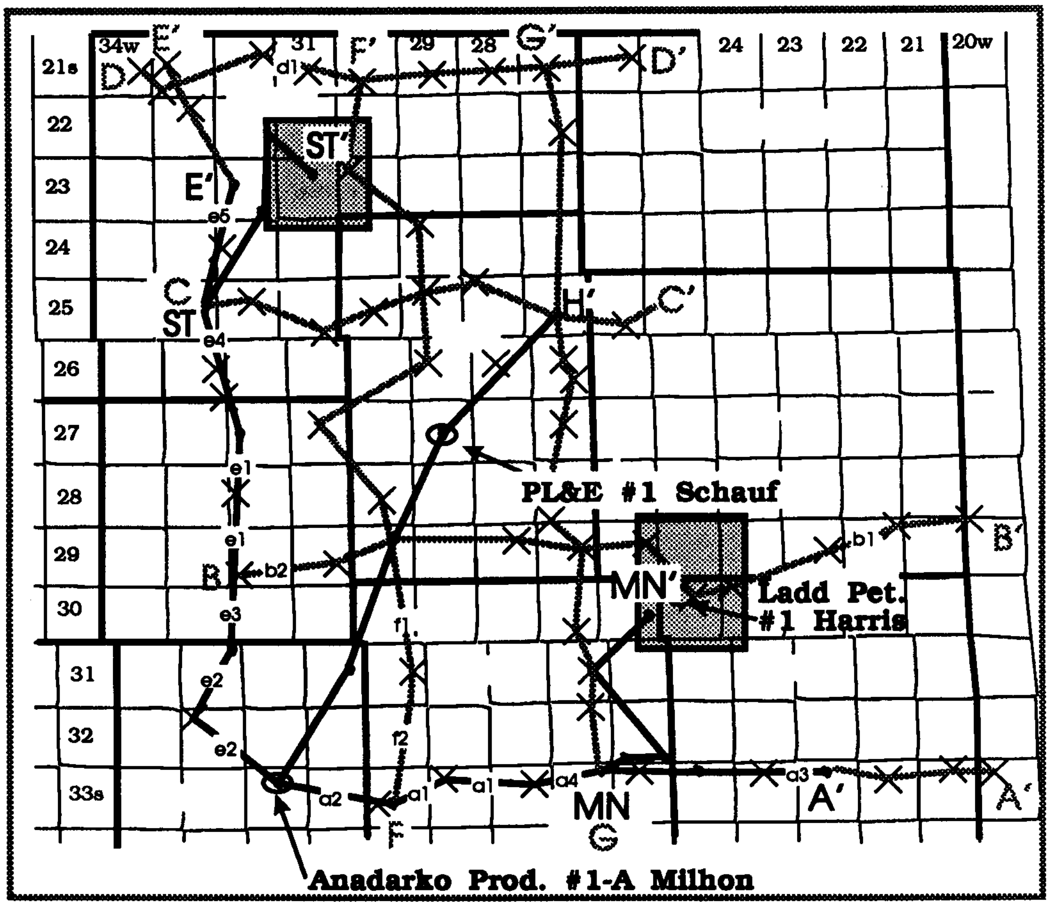

Fig. 2 Regional cross sections used in this investigation (Youle, 1992). Black dots and thicker black lines denote wells and cross-sections presented in this report. Crosses and gray lines indicate other wells and cross sections used in this investigation.
Small letters with numbers indicate locations of fine-scale cross-sections (average 1 mile between wells). Light gray areas indicate field study areas.

CHAPTER TWO

GENERAL GEOLOGY

Tectonic Setting

The Hugoton embayment is a spoon-shaped basin located in western Kansas and eastern Colorado that plunges southward into the Anadarko basin of Oklahoma. The depression began to develop in the late Cambrian or early Ordovician (Rader, 1987) but received its thickest accumulation of sediments during the Late Mississippian, Pennsylvanian and Early Permian (Merriam, 1963). Uplift of the Central Kansas uplift occurred during the late Mississippian; however, active subsidence of the Hugoton embayment and Anadarko basin did not begin until the late Morrowan and is associated with the collision of the North American and South American plates (Rascoe and Adler, 1983). The Hugoton embayment became inactive by Mesozoic time (Merriam, 1963). During deposition of Lower and lower Middle Pennsylvanian strata, the Hugoton embayment was bounded on the east by the Pratt Anticline and Central Kansas uplift, on the northeast by the Cambridge arch, on the west by the Apishapa-Sierra Grande uplift and Ancestral Rockies, on the southwest by the Keyes dome, and to the south by the Anadarko basin (Fig. 2).

Geologic History of Upper Mississippian and Lower Pennsylvanian Strata in the Eastern Hugoton Embayment

Uplift of the Siouxia axis, Ancestral Rockies, and the Sierra Grande uplift began during Meramecian time (Clair and Volk, 1968: DeVoto, 1980a). These tectonic events, coupled with a lowering of eustatic sea-level (Mitchum, Vail and Thompson, 1977), resulted in the punctuated regression of Late Mississippian seas. The first evidence of Mississippian regression in the Hugoton embayment is the presence of evaporites, eolianites and intraformational conglomerates in the upper Middle Mississippian St.Louis Limestone (Abegg, 1991). The first prominent quartzose sandstones and coarse-grained conglomerates were introduced into the shallow marine platform of western Kansas during the Chesterian Age (Late Mississippian), and indicate erosion of the positive features ringing the Hugoton embayment (Abegg, 1991). The end of the Mississippian and beginning of the Pennsylvanian Period is characterized throughout the Mid-Continent by regional uplift, folding, faulting and erosion (Rascoe and Adler, 1983). The Central Kansas uplift, Cambridge arch and Ancestral Rockies became prominent positive features during this time. In the eastern Hugoton embayment extensive erosion formed many south- to west-trending valleys.

Lower and lower Middle Pennsylvanian rocks are characterized by cyclic marine transgression. Limestones, shales and marine sandstones of the lower Kearny were the first sediments to onlap the sub-Pennsylvanian unconformity surface (McManus, 1959). Lower Morrow (Kearny) strata are overstepped by upper Morrow (Kearny) limestones, shales, coals and fluvial-estuarine sandstones (Swanson, 1979). Wheeler et al. (1990) identified seven valley-fill systems within upper Morrow (Kearny) strata in southeastern Colorado and southwestern Kansas. Regionally extensive limestones and black shales of the "Gray group" disconformably overlie and overstep the Kearny in the eastern Hugoton embayment.

Evolution of Lower and lower Middle Pennsylvanian Stratigraphic Nomenclature in Western Kansas and Previous Investigations.

Lower and lower Middle Pennsylvanian stratigraphy in the eastern Hugoton embayment is poorly defined and confusing due to a lack of biostratigraphic control and regional studies. The following sections describe the evolution of stratigraphic nomenclature and interpreted geologic relationships between lower and lower Middle Pennsylvanian rocks in the Hugoton embayment of Kansas.

Identification of Morrowan-age Strata in Kansas

The first identification of pre-Cherokee rocks in southwestern Kansas was made by Thompson (1944). He identified pre-Cherokee rocks on the basis of four species and one variety of the fusulinid *Millerella*. These fusulinds were discovered in core from the Stanolind #1 Patterson, section 23 of T22S R38W, Kearny County. Based on the presence of *Millerella,* and a lack of other fusulinids, Thompson correlated the strata below the productive "Patterson Sandstone" and above the Mississippian (Ste. Genevieve Limestone) to the type Morrowan section described by Adams and Ulrick (1904) near Morrow, Arkansas. Thompson named the interval the Kearny Formation.

McManus (1956) redefined the upper limit of the Kearny in the Patterson #1 as occurring above the "Patterson Sandstone" and at the base of the "Atokan Series" carbonates. He informally recognized upper and lower Kearny members based upon their lithostratigraphic characteristics. The thinner lower member consists predominately of glauconitic sandstones and dark gray to black shales, and is commonly capped by an arenaceous limestone or calcareous sandstone. The upper member oversteps the lower toward the Central Kansas uplift, and is recognized by the presence of thick dark colored sandy shales and locally thick sandstones lenses.

Identification of Atokan-age Strata in Kansas

The first report of Atokan-age rocks in Kansas was made by Maher (1947). According to Maher (1947), Henbest correlated fusulinids in drilling samples from the western tier of counties in Kansas and eastern Colorado, to the fauna of the Atoka Formation of Oklahoma (Maher, 1947, 1948). The name Atoka Formation was introduced by Taff (1902) to describe about 7000 feet of sandstones and shales near the town of Atoka, Oklahoma (Huffman, 1959). Maher (1947) termed the rocks correlated to the Atoka Formation the "Atokan Series", and described them as alternating beds of brown to black cherty limestones interbedded with beds of hard black shales. However, according to Maher (1947, 1953) biostratigraphic control was insufficient to resolve the upper and lower boundaries of the "Atokan Series". Consequently, he "arbitrarily" placed "Atokan Series" boundaries at the nearest clastic units above and below the fusulinids; believing that they represented unconformity surfaces.

Maher (1947) did not believe that rocks belonging to the "Atokan Series" extended as far east as the type section of the Kearny Formation. In the type Kearny section, Maher (1947) depicted the Cherokee Group of the "Desmoinesian Series" as lying unconformably upon the Kearny Formation of Morrowan age. This is the first suggestion that Atokan-age rocks offlap Morrowan-age rocks in Kansas.

Subsequent Investigations

Lee (1953) reported the presence of one silicified *Fusulinella* in a limestone above the Kearny Formation in the Stanolind #1 Adams, 8-35s-30W, in Meade County, Kansas. According to Lee (1953), Lalicker considered the fusulinid to be Atokan in age. Lee described the "Atokan Series" as gray, black and brown limestones interbedded with black to dark gray shales. Lee, like Maher before him, "arbitrarily" placed the upper and lower contacts of the "Atokan Series" at the base of clastic zones thought to represent unconformity surfaces. Lee's work effectively expanded the extent of Atokan-age rocks from the western tier of counties in Kansas eastward at least as far as Meade County.

McManus (1956), using lithostratigraphic correlation techniques, contradicted Maher's earlier correlations and identified what he believed to be "Atokan Series" carbonates above the Kearny Formation in its type section. McManus was the first to suggest that "Atokan Series" rocks may be conformable with overlying

Desmoinesian-age Cherokee Group strata.

Huffman (1959) and Abels (1959) considered the dark limestones and interbedded black shales of the "Atoka Series" in Kansas, to be correlative with the poorly defined "Thirteen Finger" lime of Oklahoma. The "Thirteen Finger" lime was named for the thirteen resistivity kicks that appear on electric logs in the Texas and Oklahoma panhandles (Jordan, 1957). Totten (1956) and Jordan (1957) state that the "Thirteen Finger" lime is commonly considered Atokan in age; but, that Desmoinesian fusulinids have been reported from it. The correlation of the "Thirteen Finger" lime to "Atokan Series" rocks in Kansas, and its perception to be Atokan in age has become widely accepted by most recent authors (Rascoe, 1962; Mannhard and Busch, 1974; Swanson, 1979; Rascoe and Adler, 1983; etc.; Clark, 1987).

Abels (1959) pointed out the lack of biostratigraphic control within Lower and lower Middle Pennsylvanian strata in the Mid-continent and first mapped and used the name Morrow in a rock-stratigraphic sense. However, despite mapping the Morrow as a lithostratigraphic unit, Abels stated:

> "Based on the assumed relationship to the downwarping of the basin (Anadarko); on inconclusive paleontological evidence; and on

lithology, it is concluded that Morrowan sediments are offlapped by Atokan rocks, and that pre-"Cherokee" Pennsylvanian rocks in northwestern Kansas and along the extreme eastern edge of the Northern Anadarko basin are actually Morrowan in age and are overlain unconformably by sediments belonging to the "Cherokee" group."

Rascoe (1962) also lumped the shales and sandstones at the base of the Pennsylvanian into a lithostratigraphic unit he called the Morrow Group. Based on lithologic continuity, he also lumped "Atokan Series" strata with the Cherokee Group and termed the composite lithostratigraphic unit the Cherokee (Atoka) Group. Despite mapping with lithostratigraphic units, Rascoe suggested that rocks of Atokan age probably overstepped Morrow-age strata in the Hugoton embayment. Consequently, unlike Abels (1959), Rascoe did not believe that Atokan-age rocks offlap Morrowan-age rocks or that the Cherokee Group lies unconformably upon Morrowan-age units in the eastern Hugoton embayment. Rascoe believed that the "Atokan Series" and the Cherokee Group were conformable throughout Kansas.

Rascoe (1962) only recognized his composite

Cherokee (Atoka) Group in those areas where a complete section of strata occurred between the Marmaton Group and his Morrow Group. Based on this criterion, he extended the range of the Morrow Group and Cherokee (Atoka) Group east to Barber County and northeast to western Rush County.

Rascoe (1962) correlated the upper one hundred feet of the type Kearny Formation, including the "Patterson Sandstone" and the fusulinid-bearing carbonates reported by Thompson (1944) to be of Morrowan age, to the Cherokee (Atoka) Group. Rascoe did not believe that Thompson's biostratigraphic data (1944) were sufficient to conclude that the Kearny Formation was Morrowan in age. The result of this correlation appears to have been the demise of the usage of the Kearny Formation in Kansas. However, despite Rascoe's lithostratigraphic correlations and based upon Thompson's early biostratigraphic work, the Kearny Formation is still formally recognized as being Morrowan in age in Kansas (Zeller, 1968). Current workers no longer use the name Kearny Formation. Instead, most workers refer to basal Pennsylvanian sandstones in the Hugoton embayment as "Morrow", and many report these sandstones as being Morrowan in age.

Khaiwka (1973) and Mannhard and Busch (1974) reverted to using Morrow as a time-stratigraphic unit and determined that Morrowan-age sandstones and shales extended into Kansas at least as far east as Commanche County.

Mannhard and Busch (1974) considered the producing sandstones in the Harper Ranch Pool (Fig. 3) to be of Morrowan age. They also reported that Atokan-age rocks (the "Thirteen Finger" lime) thin dramatically over Morrowan-age sandstones and are separated from them by an unconformity surface in the eastern Hugoton embayment. However, they suggested that no significant hiatus existed between deposition of Atokan-age rocks and overlying Desmoinesian rocks of the Cherokee Group.

Swanson (1979), using Morrow as a rock-stratigraphic term, proposed that "Morrow" sandstones extended eastward only as far as extreme southwestern Clark County (Fig.3). He also reported that the "Thirteen Finger" lime thinned over Morrow sandstones in the eastern Hugoton and that it overstepped the "Morrow" to the north and northeast; however, he did not expound on the contact between the "Thirteen Finger" lime and the Cherokee Group.

Emery and Sutterlin (1986), using Morrow as a time-stratigraphic term, reported that Morrowan-Stage sandstones produce oil in the Lexington Pool of northeastern Clark County (Fig. 3). In the Lexington Pool, they reported that the Desmoinesian Cherokee Group

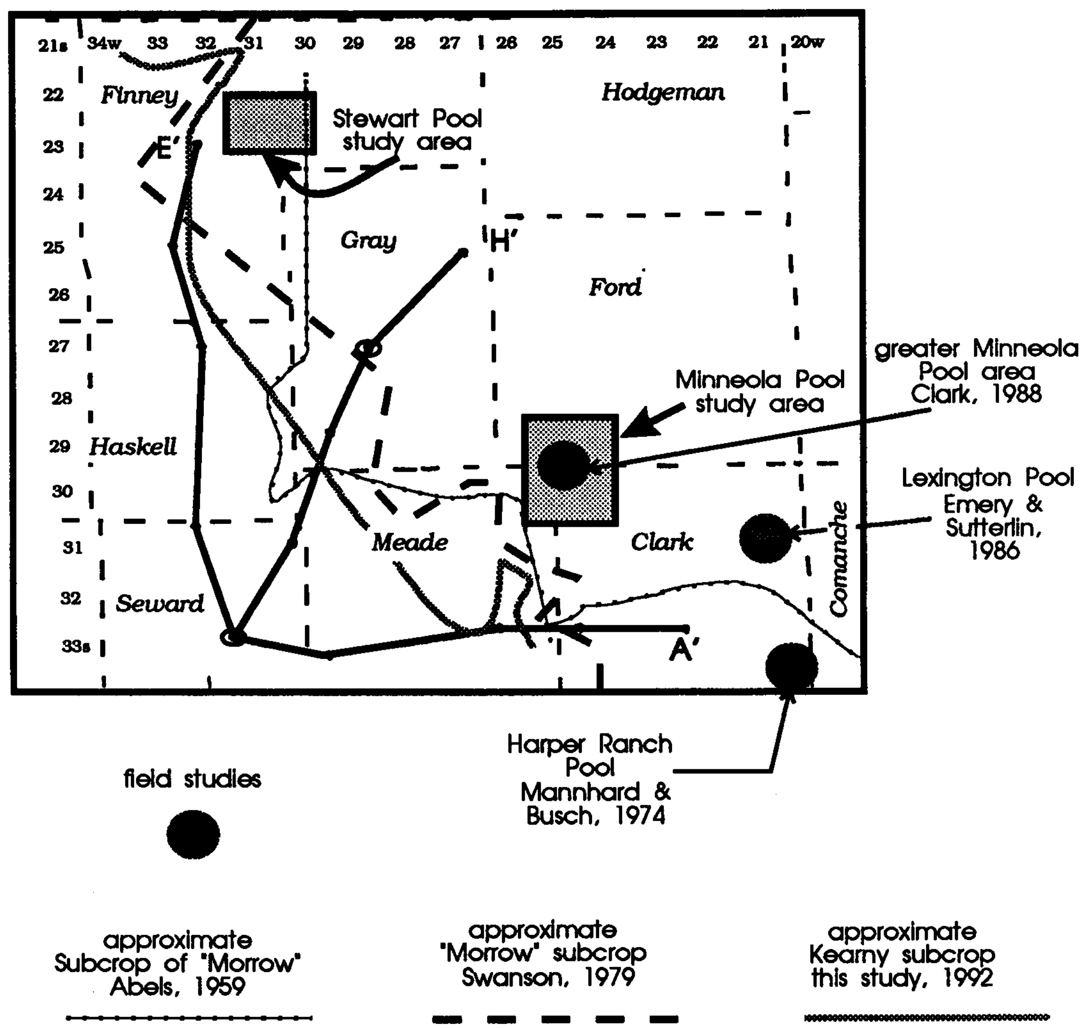

Fig. 3. Selected "Morrow" subcrops and areas of previous investigation of basal Pennsylvanian sandstones. "Morrow" or Kearny rocks are present west of the subcrop lines.

carbonates unconformably overlie Morrowan-age sandstones and that Atokan-age rocks were removed by pre-Cherokee erosion.

Clark (1987) reported that Morrowan-age sandstones are productive at the Minneola Pool in north-central Clark County (Fig. 3) and that they are unconformably overlain by Atokan-age rocks (the "Thirteen Finger" lime). Clark also reported that Atokan-age rocks are locally removed by erosion and that Desmoinesian carbonates of the Cherokee Group may lie unconformably upon Morrowan-age sandstones.

Johnson et al. (1989) refer to "Atokan Stage" rocks as the Atoka Group in the Midcontinent. They suggest that the Atoka-Morrow Group boundary is conformable in the Anadarko basin but becomes unconformable in the Hugoton embayment; and that the Cherokee Group conformably overlies the Atoka Group throughout the Hugoton embayment.

Summary of Lower and Lower Middle Pennsylvanian Stratigraphy in the Eastern Hugoton Embayment.

Investigations of Lower and lower Middle Pennsylvanian strata in the eastern Hugoton embayment have been clouded by a lack of biostratigraphic control and the use of lithostratigraphic correlation techniques for poorly constrained chronostratigraphic units. Much of the controversy regarding geologic relationships between units might have been resolved by proper attention to the difference between lithostratigraphic and chronostratigraphic units.

Many workers use the term Morrow in a time-stratigraphic sense (Maher, 1947, 1948, 1953; Khaiwka, 1973; Mannhard and Busch, 1974; Emery and Sutterlin, 1986; Clark, 1988). However, some geologists use Morrow as a rock stratigraphic term (Rascoe, 1962; Swanson, 1979; Sonnenberg et al., 1990).

A substantial number of geologists believe that Atokan-age rocks have been removed by pre-Desmoinesian erosion and that Desmoinesian-age strata lie directly upon Morrowan-age strata in Kansas (Maher, 1947, 1948, 1953; Huffman, 1959; Emery and Sutterlin, 1986, Clark, 1987). However, Abels (1959) suggested that Atokan-age rocks may never have been deposited above Morrowan-age strata in the eastern Hugoton embayment. Still other workers suggest that rocks believed to be Atokan in age are conformable with the overlying Cherokee Group and that rocks of Atokan-age onlap and overstep Morrowan-age strata (Rascoe, 1962; Mannhard and Busch, 1974).

Rascoe (1962) believed that "Morrow Group" sandstones and the "Cherokee (Atoka) Group" should be considered time transgressive lithostratigraphic units. However, later workers reverted to applying lithostratigraphic techniques of correlation to the old and poorly defined chronostratigraphic units (Mannhard and Busch, 1974; Emery and Sutterlin, 1986; Clark, 1987).

Current Terminology

The name Kearny Formation has been dropped from usage by current workers in Kansas and the oil industry. In southwestern Kansas, basal Pennsylvanian sandstones are referred to as "Morrow" by most authors (Mannhard and Busch, 1974; Emery and Sutterlin, 1986; Clark, 1988; Newell et al., 1990) and the oil industry.

Carbonates that overlie basal Pennsylvanian ("Morrow") sandstones and underlie the Marmaton Group have been separated into two units; although no boundary between them has been identified. The lower carbonate unit is not named in Kansas but is considered to represent strata deposited during the Atokan stage (Zeller, 1968). Current oil field practice in Kansas is to either apply the chronostratigraphic term Atokan or, some derivation of the lithostratigraphic term "Atoka Group" (Johnson et al., 1989) to the first appearance of thinly interbedded carbonates and shales that lie above the siliciclastic basal Pennsylvanian units referred to as "Morrow". The upper part of the carbonate-shale succession is the Cherokee Group and is commonly considered to be Desmoinesian in age (Zeller, 1968).

Biostratigraphic data are insufficient to resolve stage boundaries in the Lower and lower Middle Pennsylvanian of southwestern Kansas. Consequently, this investigation uses only lithostratigraphic units in correlation and follows Kansas nomenclature as defined by Zeller (1968; Fig. 4).

Based on detailed correlation of wireline logs and application of sequence stratigraphic methods, this investigation concludes that producing basal Pennsylvanian sandstones in the eastern Hugoton embayment are the updip siliciclastic equivalents of carbonates commonly referred to as the "Atokan Series" by early workers (Maher, 1947, 1948, 1953; Lee, 1953; McManus, 1959; Huffman, 1959;) or the Atoka Group by modern workers (Johnson et al., 1989). The age of these sandstones and their equivalent carbonates has not been determined. They are younger than the producing sandstones called "Morrow" in the Anadarko basin, Panhandle regions of Oklahoma and Texas, or Colorado-Kansas stateline area, and are older than basal Pennsylvanian sandstones and conglomerates called

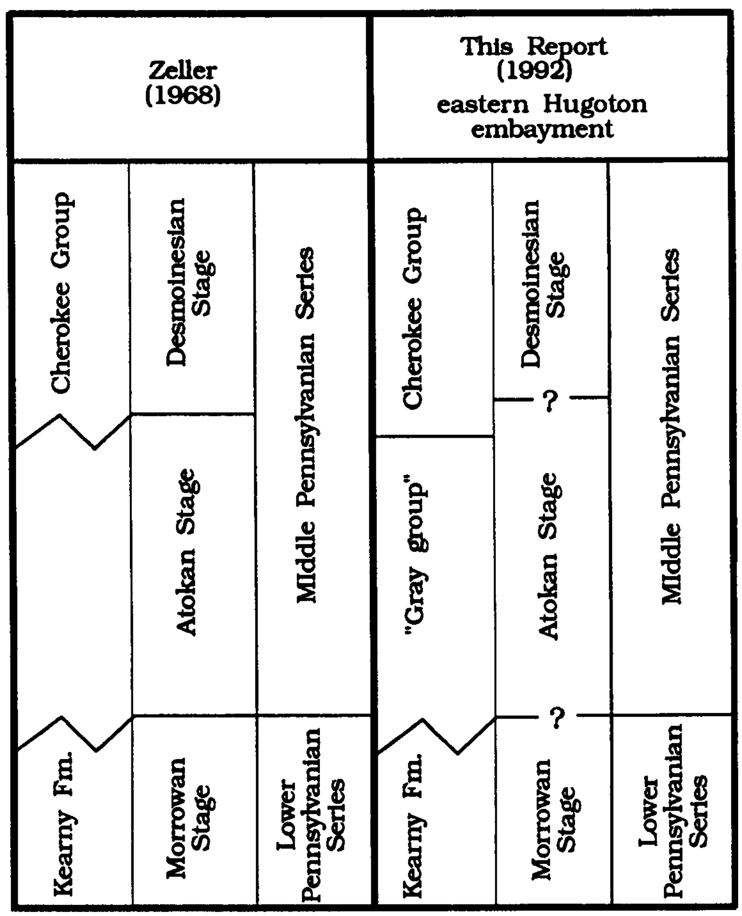

Fig. 4 Stratigraphy of Lower and lower Middle Pennsylvanian rocks in western Kansas.

"Cherokee", on the flank of the Central Kansas uplift, in Ness, Rush, Trego and Pawnee Counties.

Proposed Revision to lower Middle Pennsylvanian Stratigraphy in Western Kansas

In this investigation the name "Gray group" is used in place of "Atoka" in *lithostratigraphic* descriptions of dubious Atokan-age strata in Kansas for three reasons: 1) the carbonates and thin shales of the "Gray group" bear little physical resemblance to the Atoka Formation of Oklahoma, 2) to avoid confusion between lithostratigraphic and chronostratigraphic units and, 3) because the biostratigraphy is incomplete.

Type Section of the "Gray group"

The proposed type section of the "Gray group" is from core depths 4877′ to 4958′ in the Pendleton #1 Schauf, located in the SW SW NE of 16-27s-29w, Gray County, Kansas (corresponding log depths are from 4871′ to 4952′ on the Pendleton #1 Pendleton; Fig. 5). Subsequent to coring, but prior to final printing of wireline logs, Pendleton Land & Exploration purchased the mineral rights on the Schauf lease and renamed the well the #1 Pendleton. The entire thickness of "Gray group" rocks in the eastern Hugoton embayment is not present in

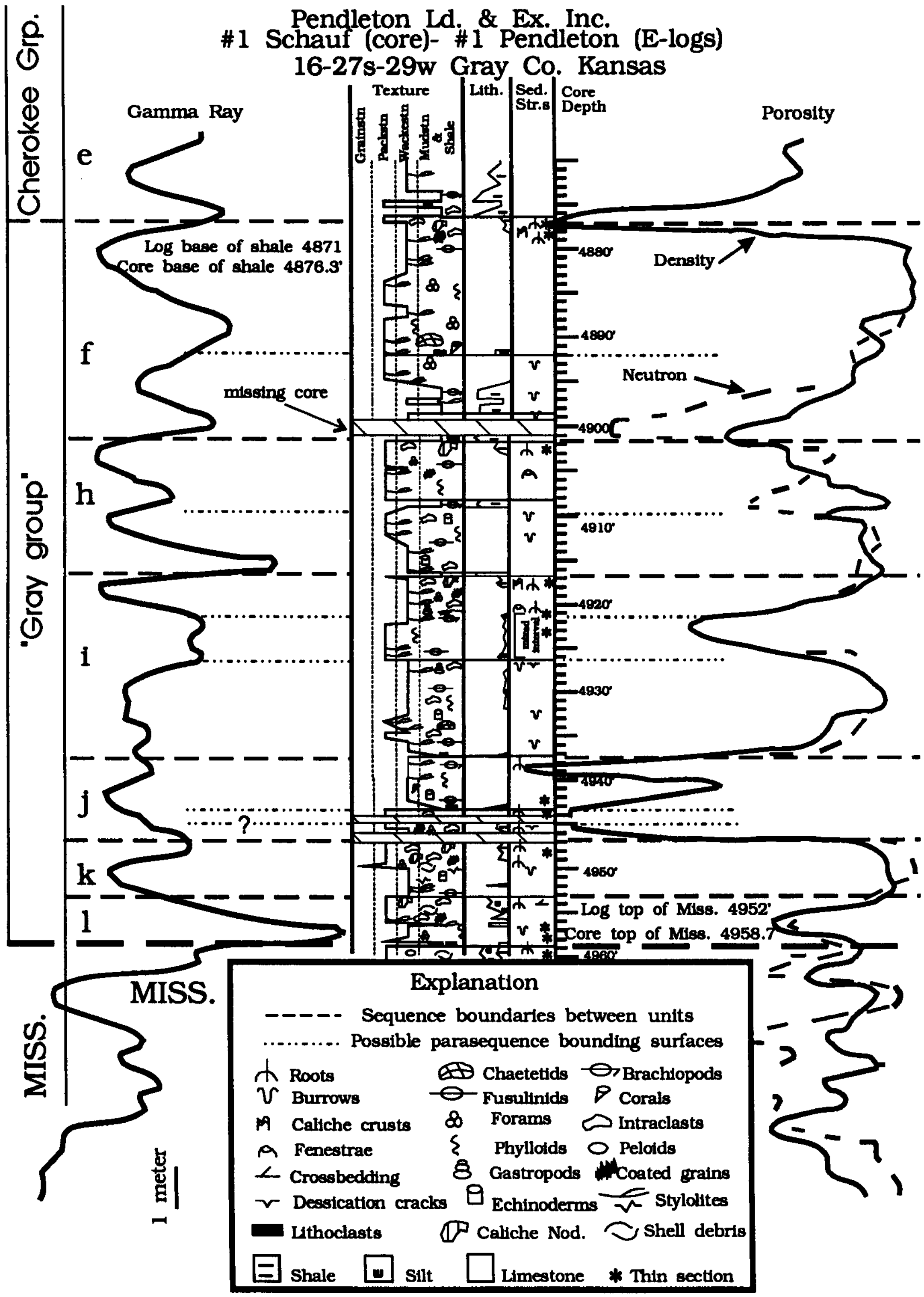

Fig. 5 Core description and wireline log of "Gray group" type section.

the #1 Schauf. Consequently, the wireline log interval from 5416′ to 5554′ in the Anadarko Production #1-A Milhon, located in the SW NE of 9-33s-32w, Seward County, is presented as an additional reference section (Figs. 6,7 & 8).

The "Gray group" comprises rocks from the top of the "*f*" sequence down to the top of the Kearny or the sub-Pennsylvanian unconformity surface (Figs. 6,7 & 8), and includes rocks correlative with the "Thirteen Finger lime" of Oklahoma. In the eastern Hugoton embayment, the top of the "*f*" sequence can be readily recognized on wireline logs at the top of two thin limestone-black-shale couplets (10 to 15 ft., 3 to 4 m thick) located about 150 feet above the Kearny (Figs. 6,7 & 8). The top of the "Gray group" also lies immediately below a prominent black "hot" shale bed. The thin black-shale-limestone couplets of the "*f*" sequence change to the north and east into a thick carbonate bed (up to about 40 ft thick) that is readily recognizable on wireline logs despite the pinch out of the overlying black shale (Figs. 6,7 & 8). To the north and east the base of the Cherokee Group can be easily identified as occurring at the base of a succession of thinly bedded shaly limestones lying immediately above the more massive dense limestones of the "Gray group" (Figs. 6,7 & 8).

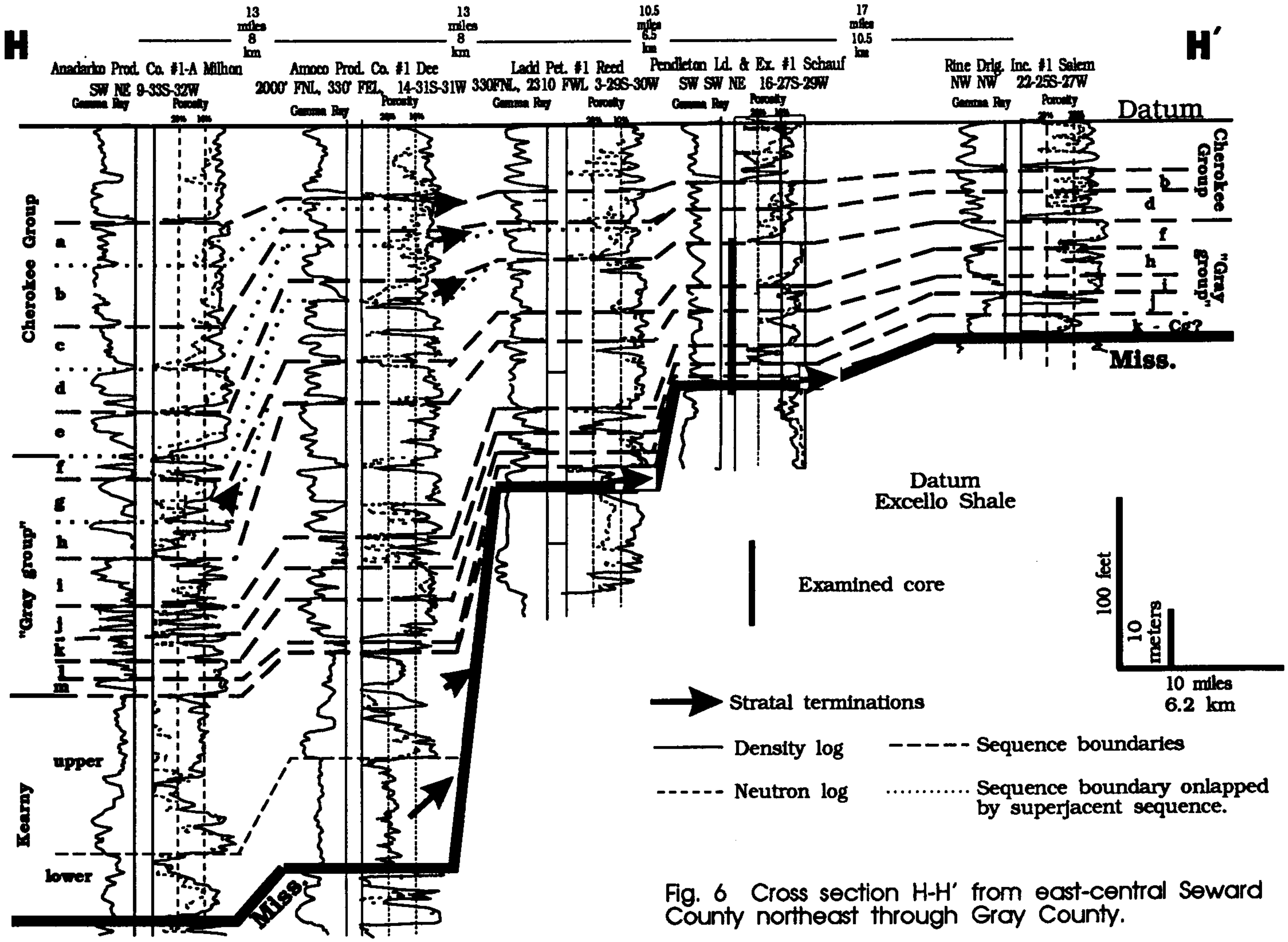

Fig. 6 Cross section H-H' from east-central Seward County northeast through Gray County.

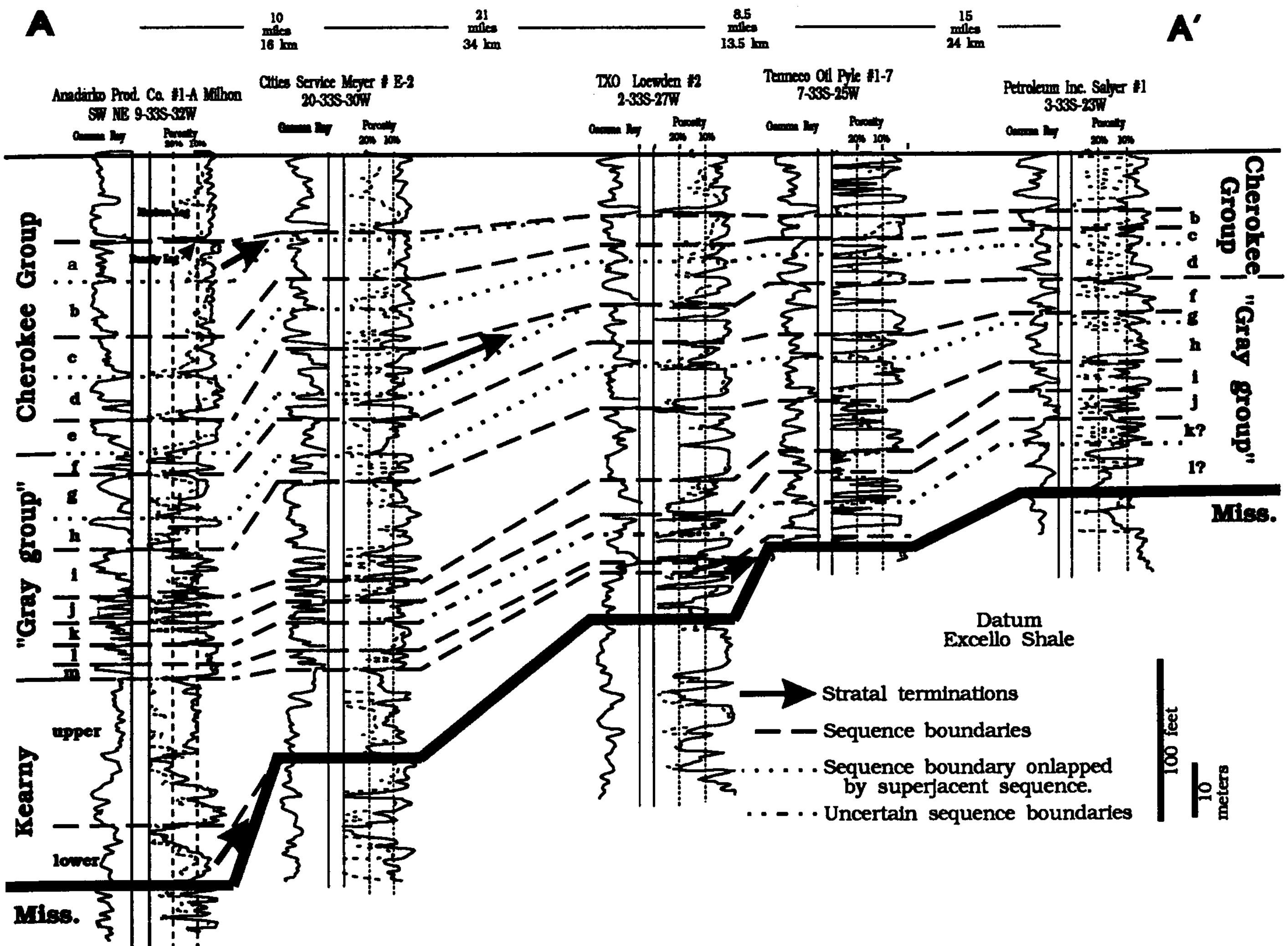

Fig. 7 Cross section A-A′ from east-central Seward County east to mid-Clark County.

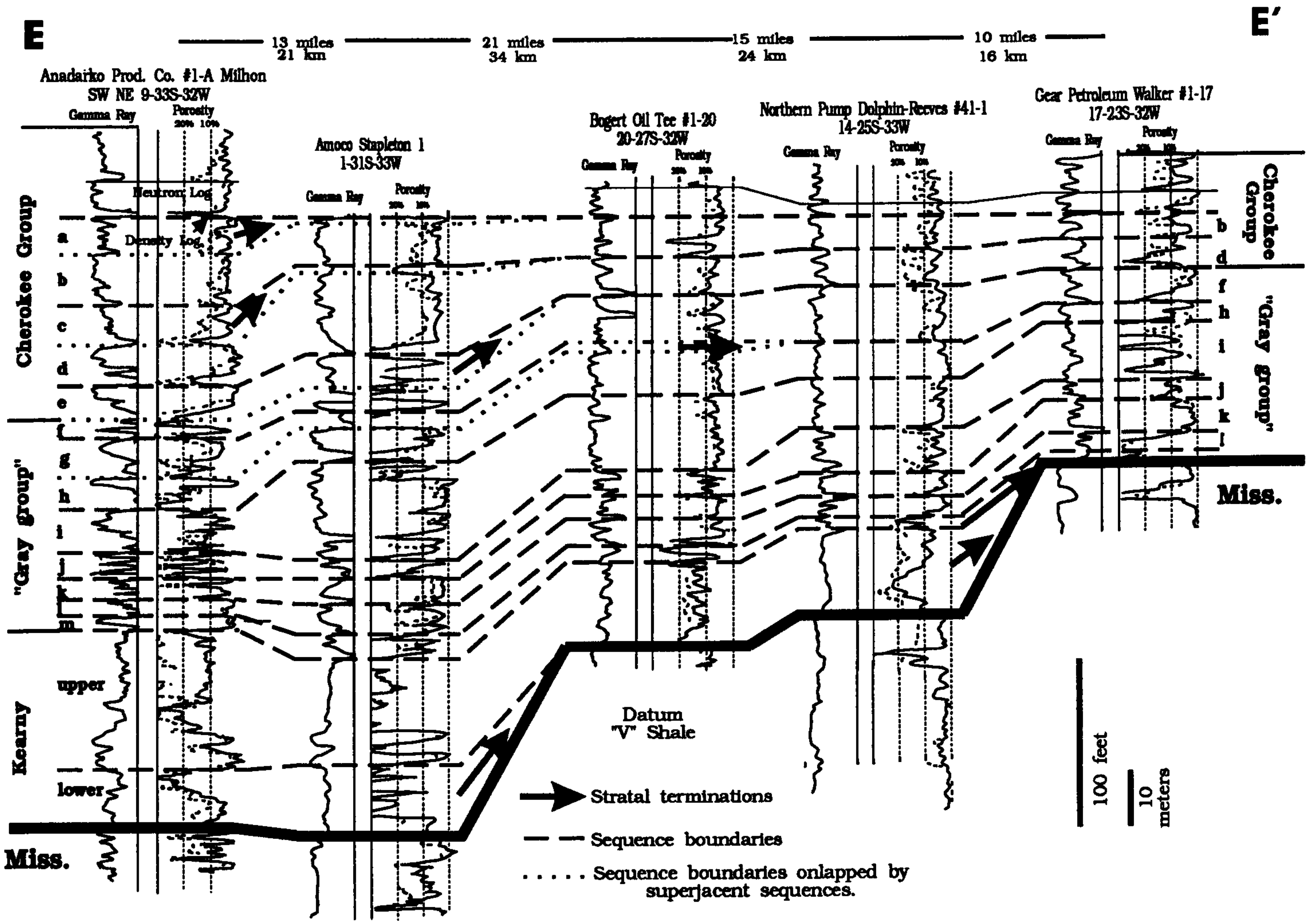

Fig. 8 Cross section E-E′ from east-central Seward County north to mid-Finney County.

CHAPTER THREE

THE "GRAY GROUP"

Description and Interpretation of "Gray Group" Lithofacies in the #1 Schauf Core

The Schauf core (section 16, T27S, R29W; Gray County, Kansas) was described in detail from 4873′ (top of "Gray group") down to 4962′ (1.25 m into the Mississippian; Fig. 9). The "Gray group" is divided into six distinct types of lithofacies, each of which represents a different environment.

Mississippian

The top 1.25 m of Mississippian strata consists of a moderately well-developed soil profile. Root molds and caliche nodules are present within a green silty peloidal packstone (Fig. 10). The contact between Mississippian and Pennsylvanian strata is sharp (Fig. 11).

Dark-Gray to Black Lithoclastic Packstone and Shale Facies (LP—SH)

Description.— Facies LP-SH occurs in layers up to 2 feet thick (61 cm) and all but one occurrence includes two distinct rock types. The base of facies LP-SH

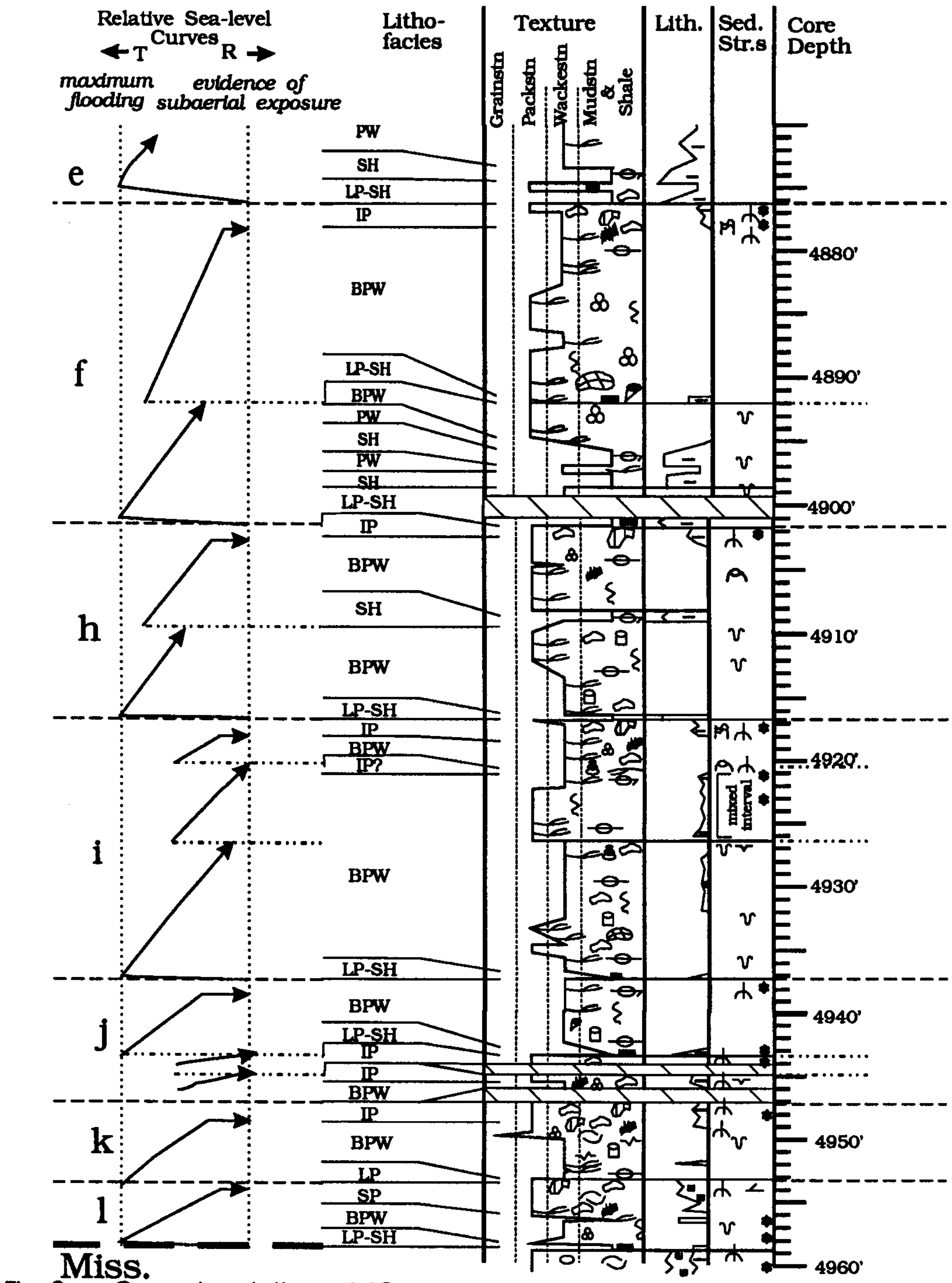

Fig 9. Core description of "Gray group" rocks in the Pendleton Ld & Ex. #1 Schauf, sec. 16 T27S R29W, Gray Co., Kansas. Key Fig. 5.

Fig. 10 Mississippian strata near top of Schauf core (4960-4961) showing 1) large root mold and 2) caliche nodules. Scale bar = 2 cm.

Fig. 11 Mississippian-Pennsylvanian contact in Schauf core @ 4959'. Scale bar = 2 cm.

consists of poorly sorted, angular to sub-angular lithoclasts in a dark-gray to black micritic matrix. It forms beds up to 7.5 cm thick. The lithoclasts, including reworked caliche nodules, were derived from underlying units. Fusulinids and echinoderm fragments are also locally common. These lithoclastic packstones and wackestones grade upward into a black to dark-gray shale (up to 30 cm thick) that contains localized concentrations of phosphate nodules (Fig. 12). Evidence of bioturbation is generally lacking in these shales. Facies LP-SH contains abundant silt within the matrix only where it directly overlies Mississippian strata (Fig. 11).

In most occurrences, facies LP-SH sharply overlies light-colored intraclastic packstones and wackestones (facies IP; Fig. 13); however, it also sharply overlies light-colored bioclastic packstones and wackestones (facies BPW) at the top of sequence *j*, and within sequence *f* (Fig. 9).

Wireline-log cross-sections indicate that facies LP-SH grades laterally down depositional dip into highly radioactive ("hot") black shales which are up to 3 m thick in the distal Hugoton embayment (Fig. 6).

Interpretation.- Lithoclastic packstones at the base of facies LP-SH are interpreted to have been

Fig. 12 Facies LP-SH at base of sequence f (4901-4902). Photo shows basal transgressive lag with lithoclasts (1) grading vertically into dark-gray shale and carbonate mudstone to wackestone. Scale bar = 2 cm.

Fig. 13 Photo shows sharp contact between facies IP and LP-SH at base of sequence h @ 4916.5' Scale bar = 2 cm.

reworked from immediately underlying deposits during transgression and deposited upon a ravinement surface. The poor sorting, angularity, and compositional immaturity of the lithoclasts suggests deposition without significant transport. The dark-gray to black matrix appears to contain abundant organic material, which may have filtered into the framework after transgression. The paucity of burrows and the presence of unoxidized organic-rich matrix indicate this unit was subjected to dysoxic conditions subsequent to transgression. Phosphate nodules in the shalier upper parts of the facies suggest slow depositional rates. Facies LP-SH is interpreted to represent a deepening-upward succession from a basal transgressive lag into a condensed section. Watney et al. (1989) point out that transgressive lags in midcontinent Pennsylvanian successions commonly underlie and are gradational with overlying condensed sections.

Limy Shale to Argillaceous Wackestone Facies (SH)

Description.- Facies SH consists of gray to dark-green calcareous shale that is locally interlaminated to thinly interbedded with brown to dark-gray argillaceous carbonate mudstone and wackestone. The facies is moderately to completely bioturbated. Whole, unabraded brachiopod and echinoderm fragments are the dominant allochems.

Facies SH generally lies gradationally above facies LP-SH and ranges from 92 cm to less than 30 cm in thickness. It is locally interbedded with dark-colored peloidal wackestones (facies PW; Fig. 14) or light-colored bioclastic packstones and wackestones (facies BPW).

Wireline-log correlations indicate that facies SH grades basinward into black shales which are up to 3 m thick. Lower-shelf black shales commonly grade landward into gray to dark-gray slightly burrowed shales in other Pennsylvanian units (Watney et al., 1989).

Interpretation.- Facies SH is interpreted to have been deposited below wave base near the base of the photic zone on an open marine shelf. The abundance of fine-grained material and the presence of unabraded fossils suggest still water deposition. The lateral transition from facies SH basinward into black shales and the lack of phylloid algae suggest this unit was deposited below the photic zone in relatively deep water. Similar fossiliferous, non-carbonate facies in Pennsylvanian rocks have been interpreted to represent deposition slightly below the photic zone under normal-marine to slightly dysoxic conditions (Boardman, et al., 1984).

Dark-colored Peloidal Wackestone Facies (PW)

Description.- Facies PW ranges from dark-gray to gray to brown, is burrow mottled, and locally contains abundant solution-seam stylolites (Fig. 14). Dominant allochems in facies PW include peloids, echinoderm fragments, brachiopods and, locally, fusulinids. Other foraminifera, phylloid algae, and intraclasts are less common. Allochems are generally whole and unabraded. Burrowing is moderate to extensive.

Facies PW is up to 61 cm thick and generally lies gradationally above facies SH or LP-SH, and is gradationally overlain by facies BPW. It is interbedded with facies SH at the base of sequence *f* (Fig. 9).

Interpretation.- Facies PW is interpreted to have been deposited below wave base but within the photic zone under normal marine conditions. The whole, unabraded fossils indicate Facies PW was deposited below wave base. The localized presence of phylloid algae indicates deposition within the photic zone. The moderate to extensive burrowing suggests deposition under normal aerobic to slightly dysoxic conditions (Boardman, 1984).

Medium-Gray to Tan Bioclastic Packstone and Wackestone Facies (BPW)

Description.- Tubular and encrusting forams, fusulinids, peloids, and phylloid algae are the dominant allochems in the packstones. Brachiopods, crinoids, fusulinids, and solitary corals are locally common throughout this facies but are most abundant in the wackestones. Chaetetids, bryozoans, and ostracodes are present in places. Bioturbation is pervasive throughout the facies.

Phylloid algae, mollusks, coated grains, and intraclasts become common toward the top of facies BPW. Locally, root traces extend down from overlying facies IP into the top of this facies. Solution-seam and suture-seam stylolites are common and in places are abundant (Fig. 15). Dark-gray clay is a common residue in the stylolites and may account for the high gamma ray counts within portions of this facies.

Facies BPW varies from 13.7 m to less than a meter in thickness. It gradationally overlies facies PW, SH or LP-SH, and is gradationally overlain by light-colored intraclastic packstone to wackestone (facies IP). In general, facies BPW grades from medium-gray or light-colored wackestones vertically into light-gray to tan packstones; however, facies LP-SH, PW or SH occur as

Fig. 14 Photo shows gradational contact between facies LP-SH (1), facies SH (2), and facies PW (3). Core depths 4878-4873. Jacob staff stripes = 50 cm.

Fig. 15 Heavily stylolitized portion of facies BPW resulting in formation of fusulinid packstone @ 4926'. Scale bar = 2 cm.

interbeds locally.

Interpretation.- The commonly broken but relatively unabraded allochems in the medium- to dark-gray wackestones indicate occasional reworking of sediment by storm waves and bioturbation. The occurrence of coated grains, intraclasts, and abraded bioclastic material near the top of this facies suggests periodic deposition above normal wave base. The relative decrease in abundance of corals, brachiopods, crinoids, and fusulinids, and commensurate increase in abundance of phylloid algae and mollusks up through the section suggest a decrease in water depth during deposition (e.g. Boardman et al., 1984). Facies BPW is interpreted to represent a shoaling-upward carbonate deposited from below to slightly above wave base, under normal marine conditions.

Tan-to-Cream Silty Bioclastic and Lithoclastic Packstone Facies (SP)

Description.- Facies SP is present only at the top of sequence *1* (Fig. 9), where it is about 75 cm thick. Facies SP is gradationally overlain by facies IP and is thinly interbedded with facies BPW. It contains heavily abraded allochems and lithoclasts in a silty packstone to siltstone matrix and locally displays low-angle cross-bedding (Fig. 16).

Fig. 16 Sequence l-k boundary @ 4954' showing transition from facies SP into and overlying facies IP. 1) blackened caliche nodule in thin cap of lithocalstic packstone. Scale bar = 2 cm.

Fig. 17 Photo of sequence h-f boundary showing gradational contact between facies BPW and autoclastic breccia in facies IP at the top of sequence h and sharp contact with overlying facies LP-SH of sequence f. Scale bar = 2 cm.

Interpretation.- The abraded allochems and low-angle cross-bedding indicate deposition in a high-energy environment, probably above normal wave base. Minor interbeds of the finer-grained facies BPW suggest deposition occurred in a lower-shoreface environment near fair-weather wave base.

Light-Colored Intraclastic Packstone to Wackestone Facies (IP)

Description.- Facies IP is a light-green to light-gray intraclastic packstone to wackestone. Biotic constituents include phylloid algae, brachiopods, foraminifera, mollusks, fusulinids, and are the same constituents that are present in the top of the underlying facies. Autoclastic brecciation, root molds, rhizocretions, and cream-to-dark-brown caliche crusts are common throughout the facies (Figs. 17,18,19,20 & 21). Alveolar textures, rhizocretions, and circumgranular cracking are common features seen in thin section (Figs. 22,23,24,25 & 26). Intraclasts are ovoid to polygonal in shape and range from several centimeters to less than one millimeter in diameter. The matrix is a green to light-gray, locally silty micrite that displays, in places, a clotted peloidal texture.

Facies IP ranges from less than 30 cm to about 80 cm

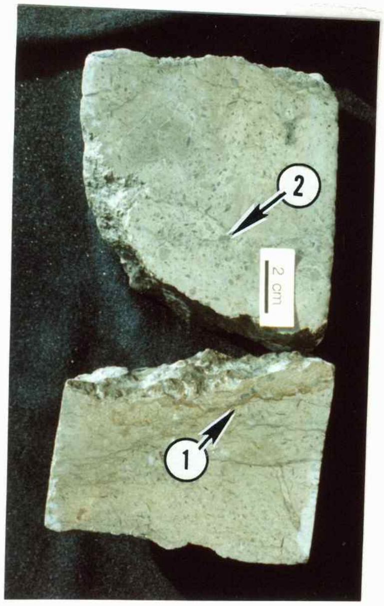

Fig. 18 Facies IP at top of sequence i, 1) caliche crust, 2) glaebuls. Scale bar = 2 cm.

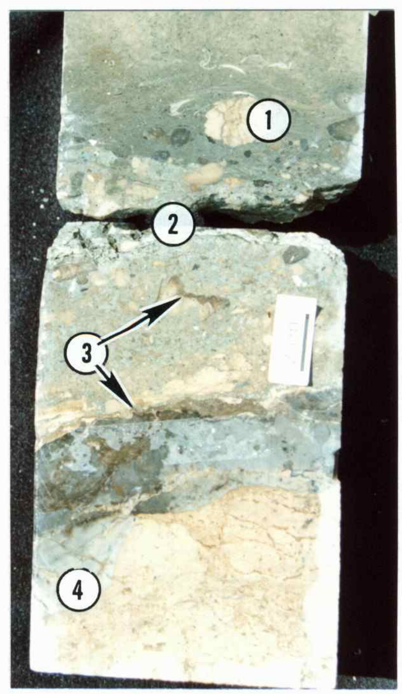

Fig. 19 Facies IP at top of sequence f @ 4977-78. 1) intragranular cracking, 2) caliche nodules, 3) caliche crusts, and 4) root molds. Scale bar = 2 cm.

Fig. 20 Facies IP at top of sequence k showing autocalstic breccia (@ 4947'). 1) caliche nodules. Scale bar = 2 cm.

Fig. 21 Green to gray slightly silty micrite filing root molds in facies IP at top sequence j. Scale bar = 2 cm.

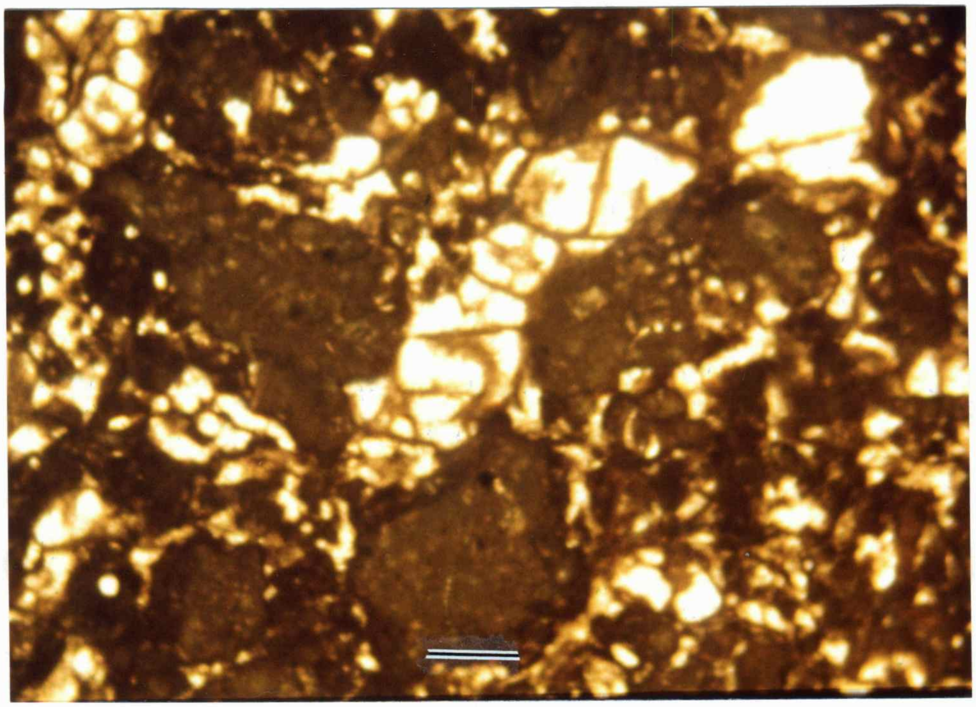

Fig. 22 Alveolar texture in facies IP @ 4878'. Scale bar = 0.5 mm.

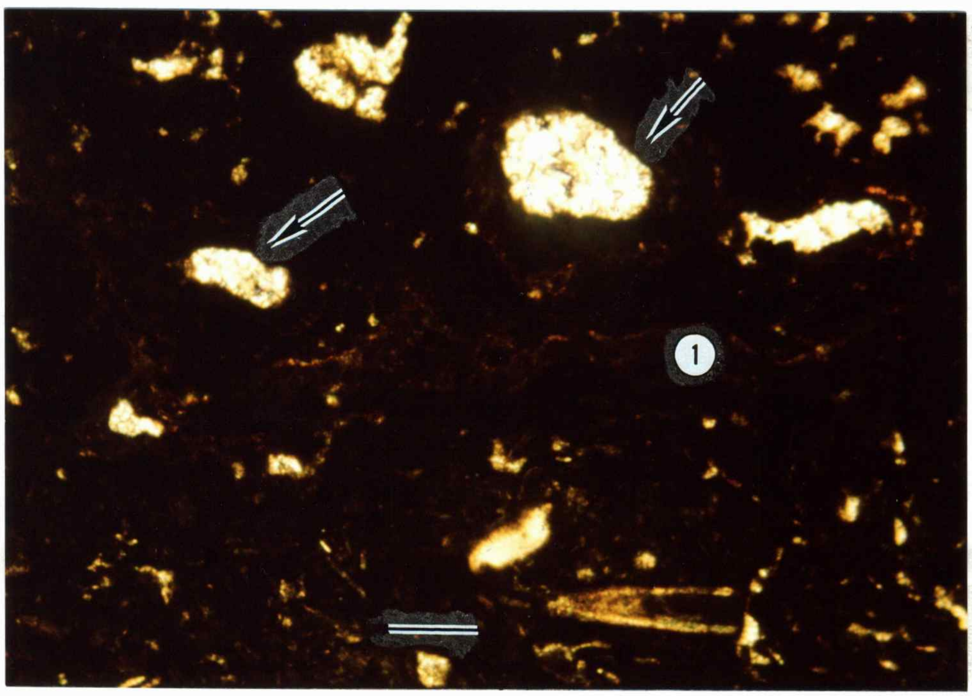

Fig. 23 Spar filled root molds surrounded by laminated caliche @ 4878'. 1) clotted peloidal caliche crust. Scale bar = 0.5 mm.

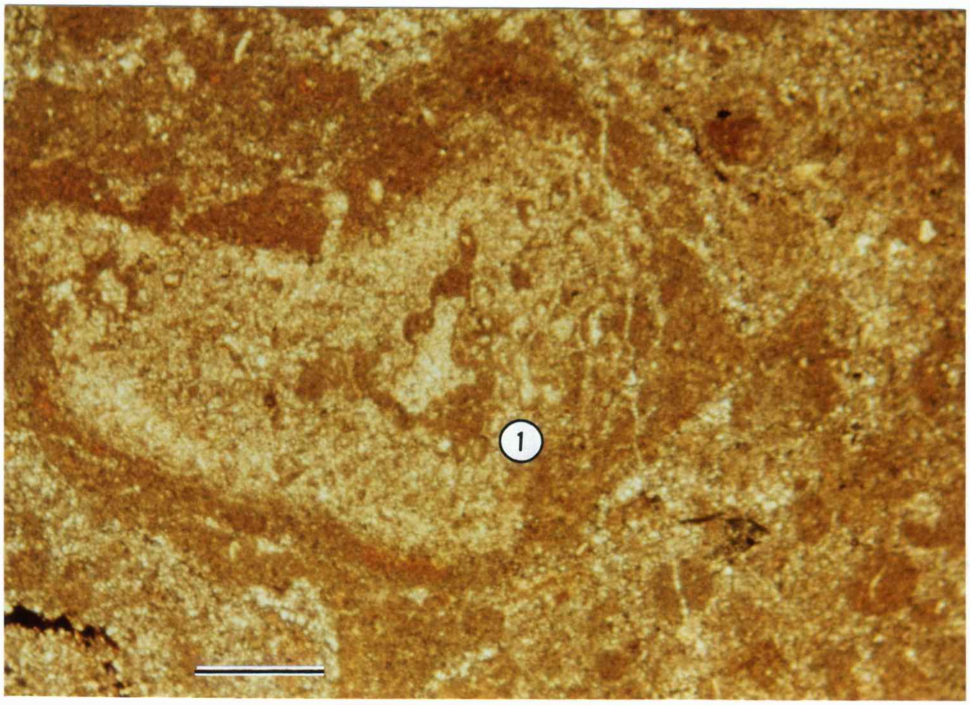

Fig. 24 Rhizocreation @ 4902' with alveolar texture (1). Scale bar = 0.5 mm.

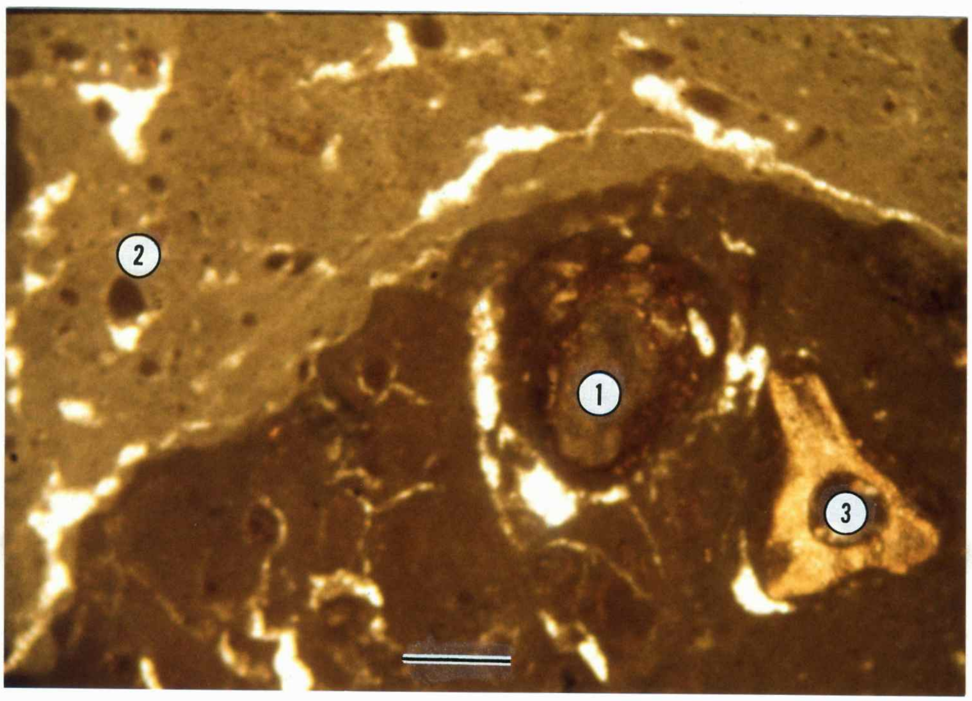

Fig. 25 Circum- and intragranular cracking @ 4916'. 1) rhizocreation with intraclasts, 2) cutans, and 3) echinoderm fragment. Scale bar = 0.5 mm.

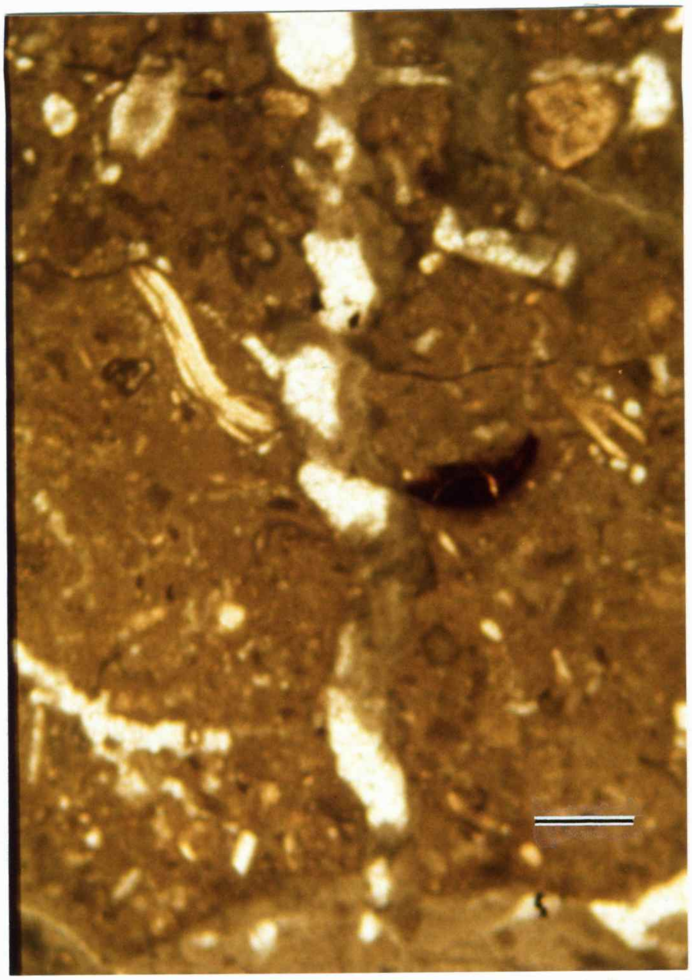

Fig. 26 Spar filled root trace penetrating intraclast @ 4916'.
Scale bar = 0.5 mm.

Fig. 27 Photo taken immediately below Fig. 19 at 4878'. It dispalys original red coloration associated with oxidation during subaerial exposure prior to gleying upon subsequent transgresssion. Scale bar = 2 cm.

in thickness. It lies gradationally above underlying facies (generally facies BPW) and is sharply overlain by the succeeding facies (generally facies LP-SH; Fig. 13).

Interpretation.- The common rhizocretions, autoclastic brecciation, root traces, caliche nodules, circumgranular cracking, and alveolar textures indicate that this facies has been altered by subaerial exposure. The intraclasts are interpreted to represent peds, created during the soil-forming process. The common green to light-gray color may be a result of post-exposure transgression and gleying of the tops of soil profiles (Joeckel, 1991). Facies IP at the top of sequence *f* displays color gradation from green and light-gray at the top, into red and tan near the base (Fig. 27); this color gradation is a common attribute of soils that have experienced transgressive gleying (Joeckel, 1991).

Geologic Relationship of the "Gray Group" to the Underlying Kearny Formation and Overlying Cherokee Group in the Eastern Hugoton Embayment

The key to understanding the relationship between "Gray group" rocks to units above and below is to establish whether the "Gray group" offlapped the Kearny or overstepped it. The cross sections shown in figures 6,7 & 8 indicate that the Kearny Formation thins and onlaps the sub-Pennsylvanian unconformity surface toward the Central Kansas uplift. These cross sections also indicate that "Gray group" rocks overstep the Kearny eastward. Core data and wireline-log cross-sections also indicate that the "Gray" and Cherokee Groups form one relatively continuous succession of strata separated by many disconformity surfaces (sequence boundaries). Consequently, this investigation concludes that the Kearny-"Gray group" boundary is disconformable, in the eastern Hugoton embayment, and that "Gray" and Cherokee Group strata form one relatively continuous succession of strata that onlaps all pre-"Gray group" rocks in the eastern Hugoton embayment. Also, detailed stratigraphic correlation indicates that certain basal Pennsylvanian sandstones are up-depositional-dip equivalents of "Gray group" carbonates. Contrary to the assertions of many recent workers (e.g. Emery, 1983; Robinson, 1983; Emery and Sutterlin; 1986; Clark, 1987), Cherokee Group rocks do not lie unconformably upon basal Pennsylvanian sandstones that are older than "Gray group" limestones.

CHAPTER FOUR

SEQUENCE STRATIGRAPHIC FRAMEWORK

Introduction

This discussion begins with a brief review of sequence stratigraphic methodology and terminology. Following this review, the assemblage of facies that constitute depositional sequences in the Schauf core will be described and interpreted. Later, facies transitions within depositional sequences along a depositional profile will be discussed, and an idealized "Gray group" sequence will be compared to the classic Kansas cyclothem described by Heckel (1977, 1989).

General Discussion of Sequence Stratigraphy

Sequence stratigraphic concepts were first developed by Exxon research personnel in the mid-'70's as a means of helping them interpret seismic data on a basinwide scale (Mitchum et al., 1977). In the '80s sequence stratigraphy was applied to interpreting outcrops and oil-well cores, also on a large scale. Most recently, combining core descriptions, seismic sections and wireline logs has aided in applying sequence stratigraphic concepts to even small-scale (oil field size) projects.

Sequence stratigraphic methods are used to divide successions of strata into temporally distinct units that may be studied independently of one another, despite lithologic similarities. The key to defining a sequence stratigraphic framework lies in interpreting the sea-level history that affected the deposition of strata studied. In any vertical section of rock, abrupt changes in sea level are often recognized by abrupt changes lithology. In core, a sequence boundary is identified at the surface where a basinward shift in facies has occurred (Van Wagoner, 1990). A basinward shift in facies is recognized when the vertical succession of lithofacies does not conform to Walther's law and the facies above a surface was deposited in a more landward position than the facies below the surface. Depositional sequence boundaries separate temporally distinct strata from one another; all rocks between sequence boundaries must be older than rocks above the top sequence boundary and younger than those below the lower sequence boundary. Wireline logs may be used to correlate sequence boundary surfaces between geographic locations despite lithologic changes above or below those surfaces. Correlations of depositional sequence boundaries help identify the spatial configurations of each temporally distinct sequence stratigraphic unit and allow facies changes within depositional sequences to be studied regionally.

Terminology

Depositional sequences are genetically related successions of strata bounded by unconformity surfaces or their correlative conformities (Mitchum, 1977). Sequence boundaries are identified by an abrupt basinward shift in facies or a change in parasequence stacking patterns (Van Wagoner et al., 1990). Van Wagoner (1990) defines a *parasequence* as "...a relatively conformable succession of genetically related beds...bounded by marine-flooding surfaces and their correlative surfaces". *Sequence sets* are groupings of sequences displaying similar progradational, aggradational or retrogradational stacking patterns (Mitchum and Van Wagoner, 1991). A *composite sequence* consists of lowstand, transgressive and highstand sequence-sets (Mitchum and Van Wagoner, 1991).

Changes in the thicknesses and facies relationships within and between depositional sequences may be a function of changes in tectonically controlled subsidence, eustatic sea-level, sedimentation rates, climate or some combination of all four. While these various factors are tantalizing, it is beyond the scope of this investigation to develop these concepts further. The remainder of this paper focuses on the description and interpretation of the gross stratal relationships of lower Middle Pennsylvanian strata in the eastern Hugoton embayment.

Sequences in #1 Schauf Core

Each of the six depositional sequences in the #1 Schauf core displays a generally consistent vertical succession of facies interpreted to reflect changes in relative sea-level (Fig. 28). Facies IP caps facies BPW and represents an abrupt basinward shift in facies from subtidal carbonates below into subaerially exposed carbonates of the same facies above (Figs. 16,17,18,19,20,21 & 28). This indicates that sea-level fell abruptly relative to carbonate depositional rates, resulting in an attenuated section that lacks intertidal and supratidal facies. Technically, the base of this facies is the sequence boundary; however, because this facies is generally too thin to be resolved on wireline logs the sequence boundary is placed at the top of facies IP for mapping purposes.

The bases of depositional sequences in the #1 Schauf are identified by the presence of facies LP-SH. Facies

#10-1 the unit is actually a red algal and sandy bioclastic grainstone and packstone (Fig. 60). The sandstone portions of the unit consist of coarse-fine couplets of sandstone and siltstone. Individual sandstone laminae (from several millimeters to a centimeter thick) are moderately well sorted and are capped by a layer of green siltstone or very-fine sandstone about 0.25 mm thick. In a few places layers of organic detritus may lie above the siltstone caps. Double drapes of siltstone and organic detritus are rare but locally present in facies D (Fig. 59). High- and low-angle cross-bedding is common, ripple-scale cross-bedding is less common. Carbonate and sandstone clasts are locally common and up to 3 cm in length. Bioturbation, soft sediment deformation features, and shales are virtually non-existent in facies D.

A layer of carbonate mudstone nodules was present in one 6 cm thick interval at the top of this facies in the Scott #4-4 (Fig. 61). The nodules contain fenestral fabrics and abundant evidence of circumgranular and intragranular cracking.

Facies D lies gradationally above facies C and is sharply overlain by facies B. It is up to a meter thick in the Scott #4-4 core but thins eastward to less than 90 cm in the Sherman #3 core. It contains about 80 cm of bioclastic grainstone and packstone in the Meyer #10-1.

Interpretation.- Facies D differs from facies B and C in that lacks shale interbeds and organic debris, and contains more high-angle cross-bedding and an abundance of coarse bioclastic debris. The presence of bioclastic debris and grainstones in this unit reflect its marine origin. The lack of suspension deposition and burrowing, coupled with the presence of high-angle cross-bedding and coarse-grained abradaed bioclasts, suggest this facies may have been deposited under higher energy conditions than other facies. The correlation between high-energy deposition and the abundance of marine organisms suggests waves may have had an important control on deposition. The double siltstone drapes are indicative of diurnal tidal deposition (Nio and Yang, 1991).

Facies D is similar to estuarine inlet deposits described by Allen (1991) in the Gironde Estuary of France. According to Allen, inlet facies consists of well-sorted medium to coarse grained sandstones that contain parallel and bi-directional cross-stratification and bioclastic debris. Clay laminae and flaser beds are absent. In the James Estuary of Virginia, bioclastic debris is restricted to bay-mouth tidal-bar sands (Nichols, Johnson and Peebles, 1991).

Facies D represents lower-estuary-bar deposition.

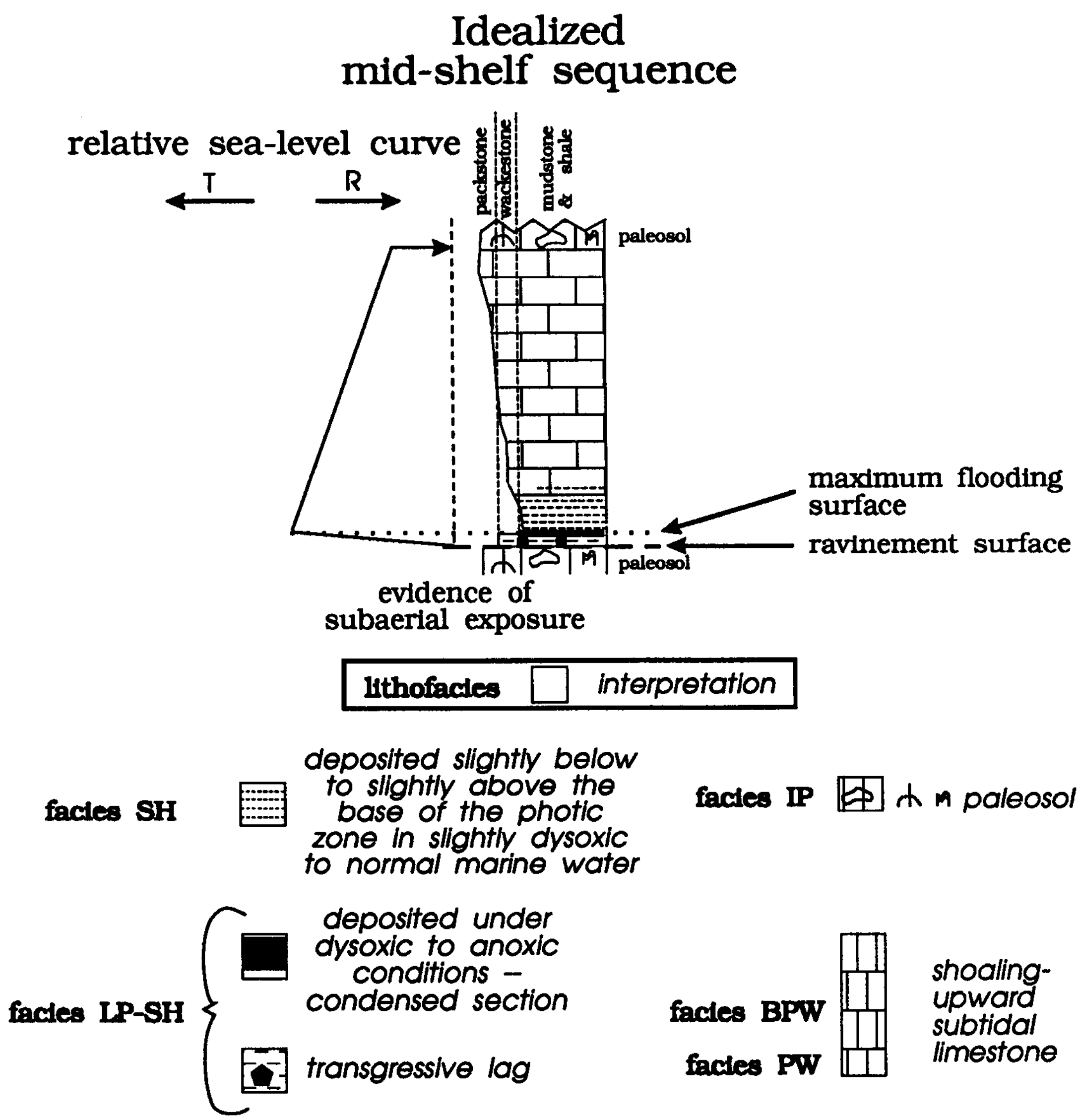

Fig. 28 Idealized mid-shelf sequence showing interpretation of lithofacies recognized in the #1 Schauf core. Use Fig. 5 as key.

LP-SH has been interpreted to represent a deepening upward succession from a basal transgressive lag into a condensed section. In general, condensed sections form when the rate of sea-level rise exceeds the rate of sediment accumulation, and represent drowning of the shelf. Condensed sections may form during transgression due to ponding of siliciclastics in source areas (Heckel, 1989) and because carbonate production is reduced due to nutrient excesses and the resulting turbidity of the water column (Neumann and Macintyre, 1985; Hallock and Schlager, 1986). Upon maximum inundation, condensed sections may continue to form due to both reduced light levels and retardation of carbonate production under dysoxic or anoxic conditions where a thermocline develops (Heckel, 1977, 1986, 1990).

Gradationally overlying facies LP-SH are carbonate-dominated facies PW or BPW. Depending on water depth, depositional topography, clarity of the water column, and water circulation, carbonates may have begun to accumulate in response to either a decrease in the rate of rise of relative sea-level, a stillstand, or a drop in relative sea-level. Facies BPW shoals upward indicating that carbonate sedimentation rates were greater than rate of relative sea-level rise or that there was a fall in relative sea-level. Technically the sequence boundary lies on top of facies BPW and at the base of facies IP.

Several minor deepening events punctuate upper "Gray group" depositional sequences and represent parasequence boundaries (Fig. 9). Depositional sequences *j*, *i*, *h* and *f* appear to be composed of multiple parasequences (shoaling upward successions of strata capped by flooding surfaces). Although parasequences can be identified in the #1 Schauf, they are generally not distinctive enough on wireline-logs to be traced regionally; therefore, parasequences are not emphasized in this report.

Figure 28 illustrates the succession and interpretation of lithofacies in the #1 Schauf core that comprise an ideal depositional sequence (one without internal parasequences). In an ideal depositional sequence, the base of each depositonal sequence is marked by a thin transgressive lag that grades vertically into a condensed section. The condensed section grades vertically into a suite of facies that are interpreted to develop under increasingly shallower water conditions (facies SH-PW-BPW). The exposure surfaces at the tops of sequences delineate depositional sequence boundaries.

Regional Distribution of Facies in "Gray group" Sequences

Depositional sequence boundaries identified in the Schauf core (Fig. 5), have been traced throughout the eastern Hugoton embayment using gamma-ray and neutron-density wireline logs. These cross sections (e.g. Figs. 6,7, & 8) were employed to observe lateral facies transitions within depositional sequences at three points along a hypothetical depositional profile, the lower-shelf, mid-shelf, and proximal shelf. However, the geographic location of these points change from sequence to sequence, depending on local sedimentation rates, depositional topography, climatic changes, and base-level changes.

Lower-Shelf Sequences

Cores of lower-shelf depositional sequences are not available for study; however, the wireline-log characteristics of depositional sequences *f* through *m,* in the Anadarko Production #1-A Milhon (Figs. 6,7,& 8), are interpreted to represent typical lower-shelf sequences. Lower-shelf "Gray group" depositional sequences range from 3 to 10 m in thickness. The base of each sequence is marked by a "hot" black shale or "hot" limestone from 1.25 to 3 m thick. Black shales are interpreted to have been deposited during periods of ocean-water stratification that probably occurred during rising (Calvert et al., 1987) or maximum water depths (Heckel, 1977, 1989). They have been interpreted to be condensed sections and represent drowning of the Hugoton shelf.

Most black shales grade upward into non-radioactive, dense limestones 1.25 to 6 m thick. In sequences *g* and *h*, black shales grade into less radioactive shaly limestone up to 3 m thick, before passing upward into non-radioactive dense limestones (up to 3 m thick). Carbonate production probably began when water circulation improved and oxygenated water was available at the sediment-water interface and accelerated once the sediment-water interface was within the photic zone. Lower-shelf limestones are interpreted to have accumulated in response to the fall in relative sea-level that culminated in subaerial exposure of correlative mid-shelf limestones.

Wireline-log correlations indicate that lower-shelf sequences maintain thickness and lithologic integrity along depositional strike. This suggests that lower-shelf sequence boundaries may be conformable.

Mid-shelf Sequences

Mid-shelf sequences are thicker than lower-shelf sequences, contain a greater percentage of carbonate rocks, and are separated from one another by disconformities delineated by subaerial exposure surfaces. The presence of well-developed subaerial exposure surfaces and lack of thick black shales reflect the decrease in accommodation space available to mid-shelf sequences compared to lower-shelf equivalents.

Sequences *f-i*, described in the #1 Schauf core, are interpreted to represent typical mid-shelf sequences. Lower-shelf black "hot" shales are rare in mid-shelf sequences. However, "hot" limestones are locally developed immediately below sequence boundaries in some mid-shelf limestones. These highly radioactive limestones may reflect localized concentrations of uranium in meteoric phreatic cements (Chung and Swart, 1990).

The bases of mid-shelf sequences are marked by a sharp ravinement surface overlain by a thin dark-gray to black lithoclastic packstone to wackestone and shale that grades upwards into a thicker (up to 1.2 m thick) dark-gray shale or shaley limestone. Overlying limestones display a general shoaling upward pattern. Subtidal carbonates are capped by subaerial exposure surfaces.

Lower-shelf black shales thin and grade into dark-gray to dark-green shales in the mid-shelf. These shales are commonly too thin to be recognized on wireline logs but range up to 1.2 m thick (Fig. 5). Dense lower-shelf limestones (up to 6 m thick) may thicken into phylloid algal to bioclastic wackestones and packstones (up to about 25 m thick) in mid-shelf environments. Shaly zones with low radioactivity (up to 3 m thick), locally present in some lower-shelf sequences between underlying black shales and overlying non-radioactive carbonates, thin and grade into the overlying limestone facies toward the mid-shelf (Fig.s 6,7 & 8).

Proximal-Shelf Sequences

Proximal sequences differ from mid-shelf sequences in that they are thinner, contain a suite of shallower water facies, and have been more extensively affected by subaerial processes. These differences reflect further decrease in accommodation space available to sequences on the flanks of the Central Kansas uplift.

The #1 Harris core, Ford County, Kansas (Fig. 29) contains a vertical succession of sequences, from top to base, that illustrates the lateral intrasequence facies changes from mid-shelf to proximal-shelf positions. This core is located on the edge of a valley incised into

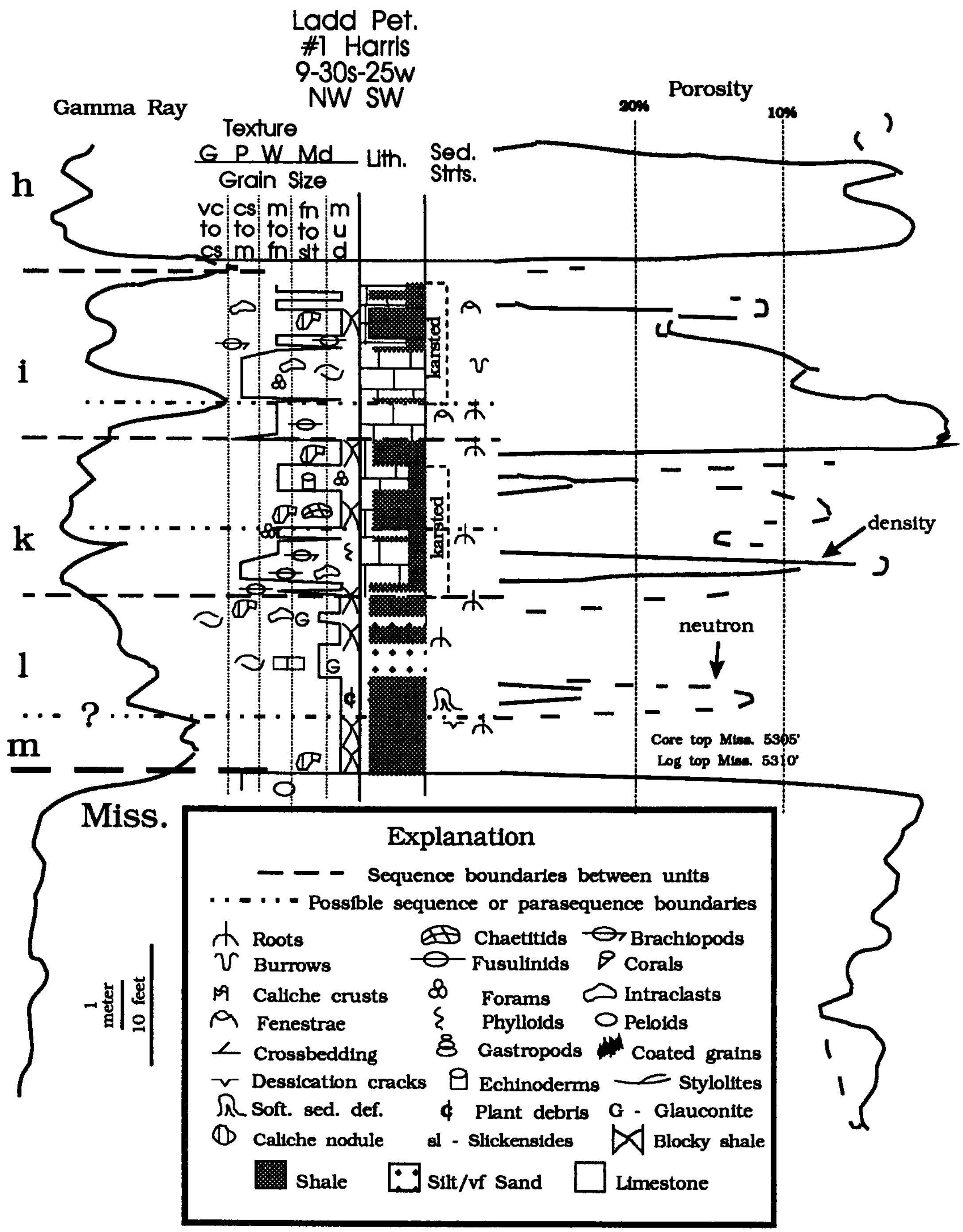

Fig. 29 Core description and wireline log of Ladd Petroleum #1 Harris displaying a spectrum of proximal-shelf facies.

Mississippian carbonates. Proximal-shelf sequences are commonly preserved in incised valleys where post-depositional erosion has not removed them, although subaerial exposure and pedogenic processes may have significantly altered them. Locally, within incised valleys, sequences *m, k, l* and *i* contain estuarine sandstones up to 18 m thick (Youle, this report Chap.s 5 & 6).

Differences between sequences in the mid-shelf and proximal-shelf environments are shown by comparing the #1 Harris to the #1 Schauf (Fig. 30). Sequence *i* thins from 6 m in the #1 Schauf to about 3 m in the Ladd Petroleum #1 Harris (Fig. 30). The manner in which sequence *i* thinned will be discussed below. Above and below sequence *i*, various forms of pedogenesis, including karsting and caliche formation, are well-developed (Figs. 31 & 32). Sequence *i* limestones in the #1 Harris are composed primarily of facies BPW and are generally similar to the facies that compose the bulk of sequence *i* in the #1 Schauf. However, in the #1 Harris, facies LP-SH and SH are not present and sequence *i* carbonates contain fenestral fabrics that are not well-developed in the #1 Schauf (Fig. 30). The lack of condensed sections in the proximal shelf sequences indicates water depth was insufficient for the development of a thermocline or to

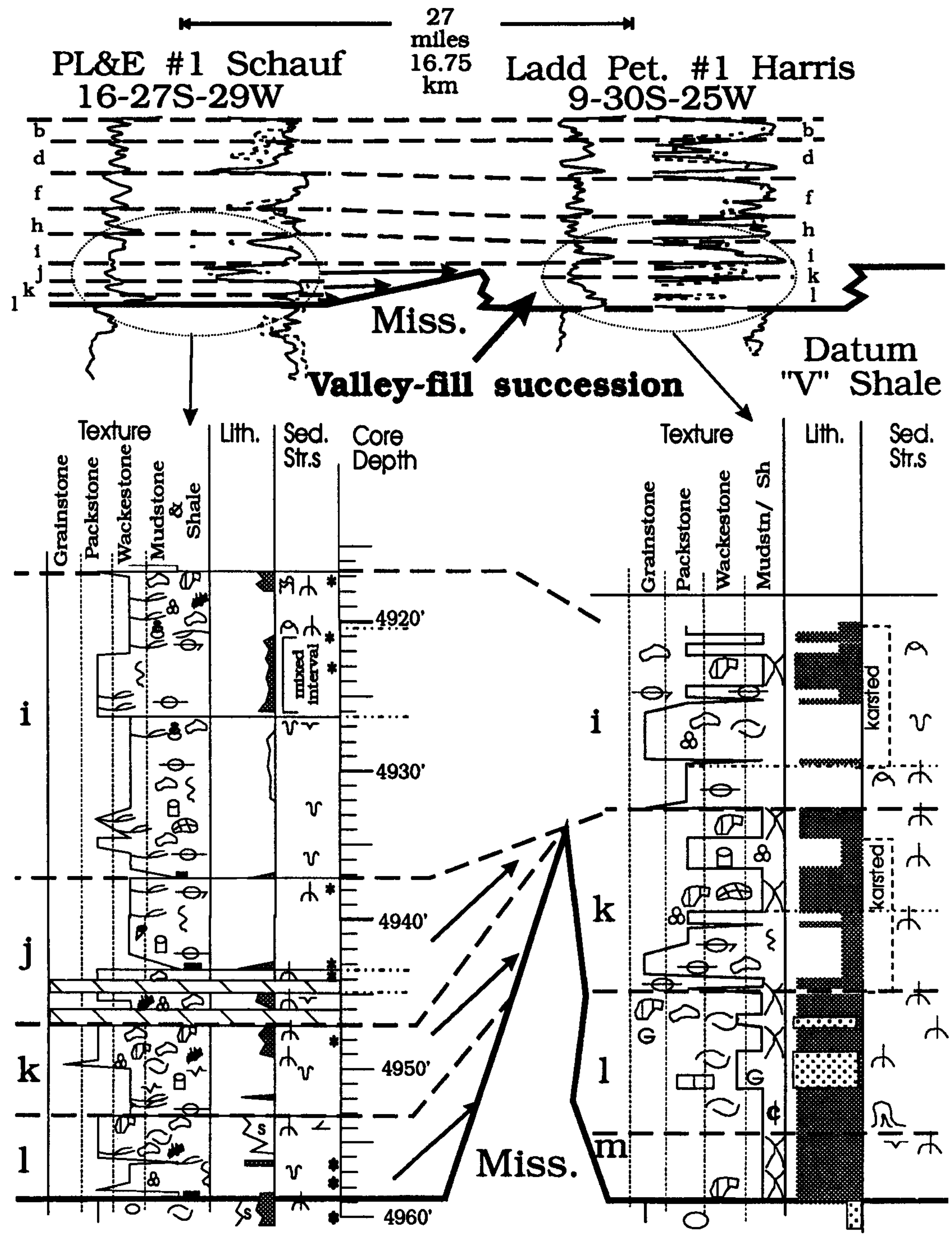

Fig. 30 Comparison of mid-shelf sequences in the #1 Schauf to proximal-shelf sequences preserved within an incised valley in the #1 Harris. Key Fig. 29.

Fig. 31 Photo displays karst fill within sequence k carbonates @ 5289' in the #1 Harris. Scale bar = 2 cm.

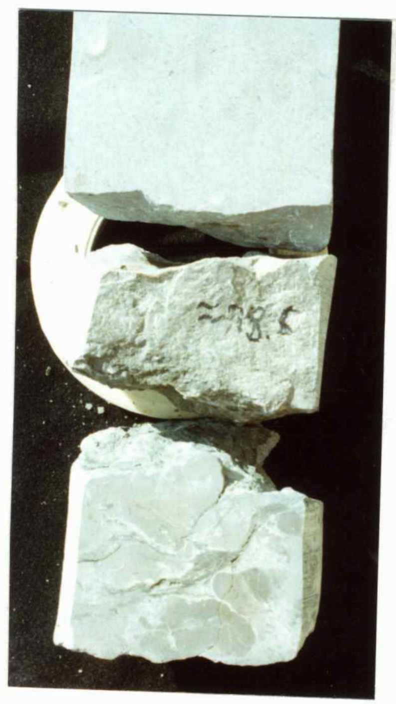

Fig. 32 Sequence i carbonates overlying karsted sequence k carbonates at 5278.5' in the #1 Harris core. Scale bar = 2 cm.

place the sediment water interface below the photic zone. The lack of facies LP-SH may also suggests that deposition began sometime after the point of maximum rate of sea-level rise and before the turn-around point on the relative sea-level curve.

The basal 15 cm of sequence *i* is a well-washed bioclastic packstone. The relative lack of mud and presence of heavily abraded, well-sorted allochems suggest this unit was deposited under high-energy conditions. This packstone grades vertically into a fusulinid-rich bioclastic wackestone with rare phylloid algal fragments. This vertical facies transition at the base of sequence *i* is interpreted to represent a deepening upward succession. The exact turn-around point of the sea-level curve in sequence *i* carbonates in the #1 Harris is difficult to establish, it occurred somewhere within the bioclastic wackestones that separate the basal packstone from overlying fenestral carbonates.

Individual soil profiles below sequence *i* in the #1 Harris core are difficult to distinguish from one another; consequently, correlation of the *k*,*l* & *m* sequence surfaces to the #1 Schauf was aided by closely spaced wireline-log correlations. Two relatively well-preserved limestone beds (60 and 120 cm thick respectively) are present about 60 cm below the base of sequence *i*. Despite the karsting within these carbonates (Fig. 31), fossils of stenohaline open-marine organisms (e.g. crinoids and brachipods) are present. The limestones are separated by about 1 m of green blocky shale with slickensides, caliche nodules, intraclasts, lithoclasts, and disoriented cheatetids. This shaly interval is interpreted to represent karst fill. The two limestones and intervening shale are proximal equivalents to sequence *k* limestones in the Schuaf core (Fig. 30).

Below sequence *k* carbonates in the #1 Harris core, are two beds of calcareous siltstone to very fine sandstone. The beds are 30 and 45 cm thick, respectively. Both siliciclastic beds contain minor amounts of lithoclasts and abraded shell fragments, and display root traces at their tops. The layers are separated by about 60 cm of blocky shale with slickensides and caliche nodules. The siltstones are interpreted to represent the low-energy estuarine or strand-line equivalents of sequence *l* carbonates in the Schauf core (Chapter 5, this paper).

The lowermost siltstone grades down into about one meter of medium-gray, slightly silty, shale at the base of sequence *l*. The shale contains small calcareous nodules, and locally, shell fragments and plant material. Evidence for subaerial exposure of this shale prior to the deposition of the overlying siltstone is equivocal. A coal up to 15 cm thick is present at the base of sequence *l* one mile to the west of the Harris core.

In the Harris core, the gray shale at the base of sequence *l* lies sharply on top of a green and red mottled, slightly silty, blocky shale with root molds, caliche nodules and, locally, shell fragments. This green and red mottled shale is about a meter thick and is interpreted to represent a soil profile that formed during deposition of sequence *m*.

The vertical succession of strata, from the base of the #1 Harris core through sequence *i*, may be characteristic of the lateral intrasequence changes in facies from proximal to mid-shelf positions. Mid-shelf carbonate beds appear to grade shoreward into karsted, thin subtidal to upper intertidal carbonates before passing further shoreward into quartzose strand or estuarine units, or merging into undifferentiated soil profiles.

Spatial Configurations and Distribution of Sequences

Figure 33 displays the generalize shape of "Gray group" depositional sequences along depositional dip. Lower-shelf sequences represent continuous deposition but

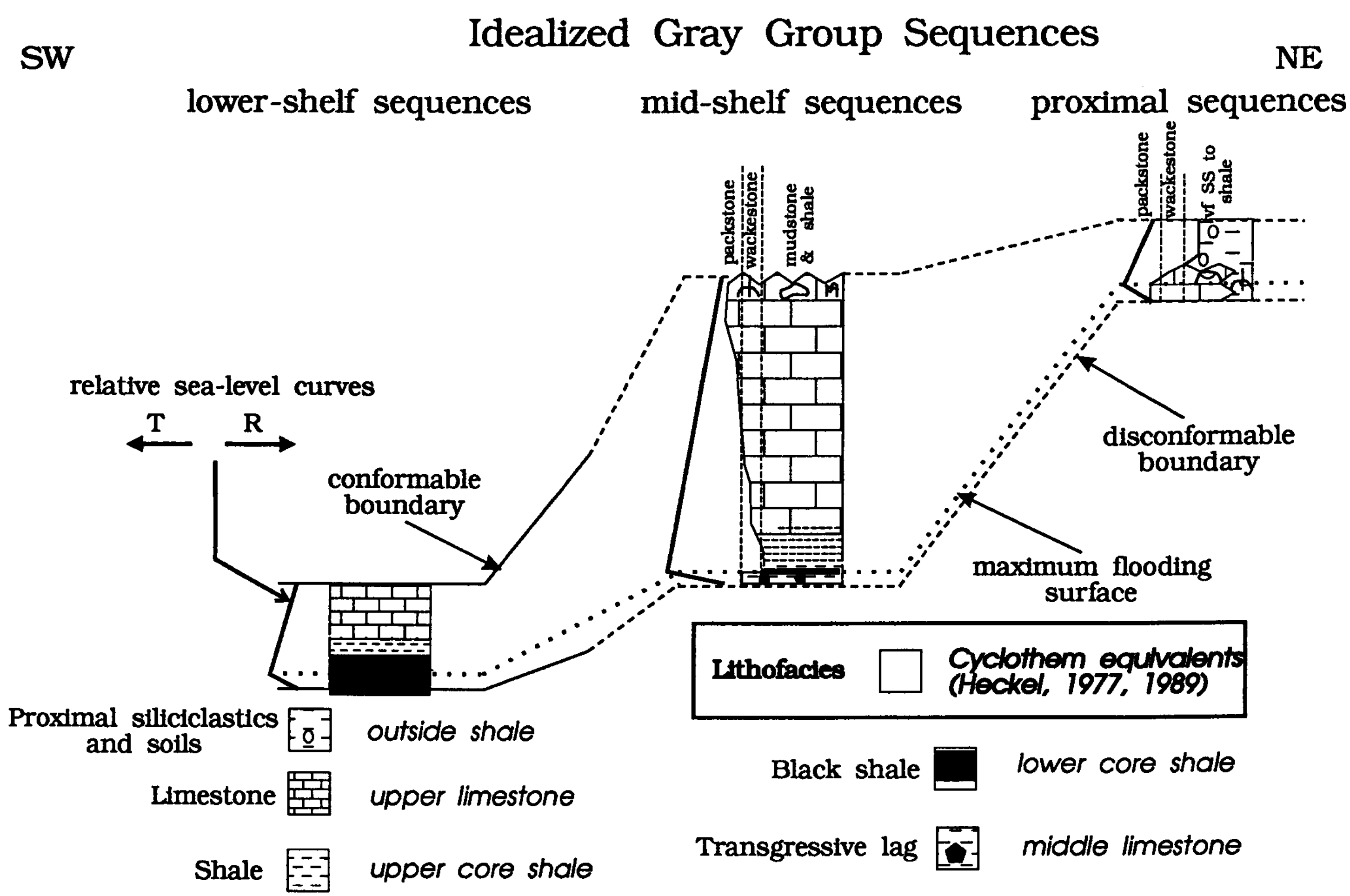

Fig. 33 Comparison of "Gray group" sequences with Heckel's cyclothems (1977, 1989).

are thin due to ocean-water stratification and the resultant retardation of carbonate production. Mid-shelf sequences are thickest because environmental conditions were conducive to carbonate-producing organisms, and carbonate deposition ceased under subaerial conditions for a relatively brief period of time. Proximal-shelf sequences are thin due to a lack of accommodation space, extensive periods of subaerial exposure and possible erosion.

Mitchum et al., (1977) identified six types of stratal terminations based upon reflection seismic records. Similar terminations can be discerned using wireline-log cross-sections. Figures 34 and 35 display correlations of limestones and shales within sequence *i* from Seward County to a position more proximal to the Central Kansas uplift in Clark County. In general, lower Middle Pennsylvanian sequences of the mid-shelf thin by downlap into the basin and thin by toplap into proximal areas. The resulting sequences are best described as sigmoidal.

Distribution of "Gray group" Sequences

Figure 36 shows the up dip extent of "Gray group" sequences in the study area. The northwest- southeast alignment of the depositional limits indicate

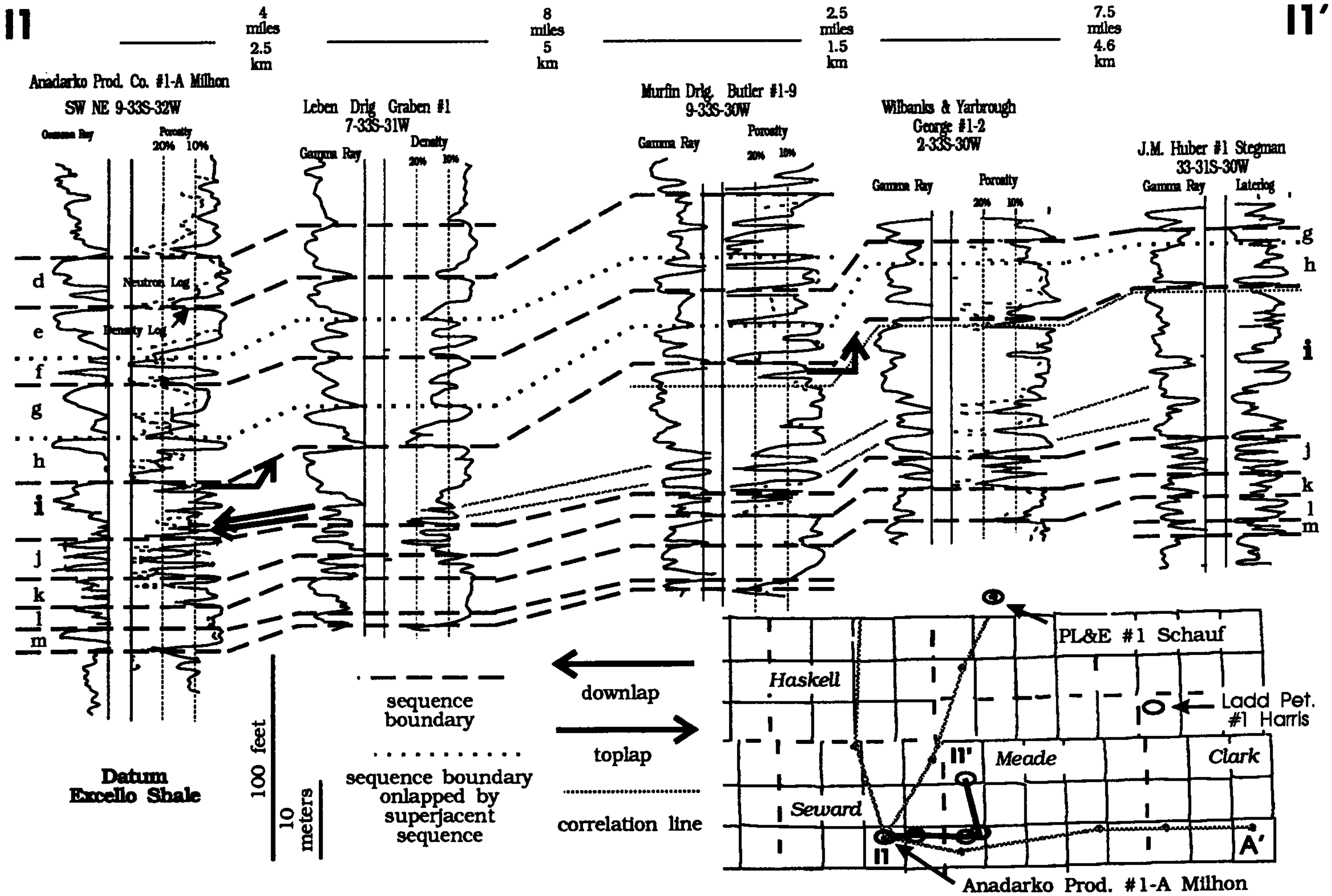

Fig. 34 Cross-section I1-I1′ displaying intrasequence i correlations from lower-shelf to mid-shelf.

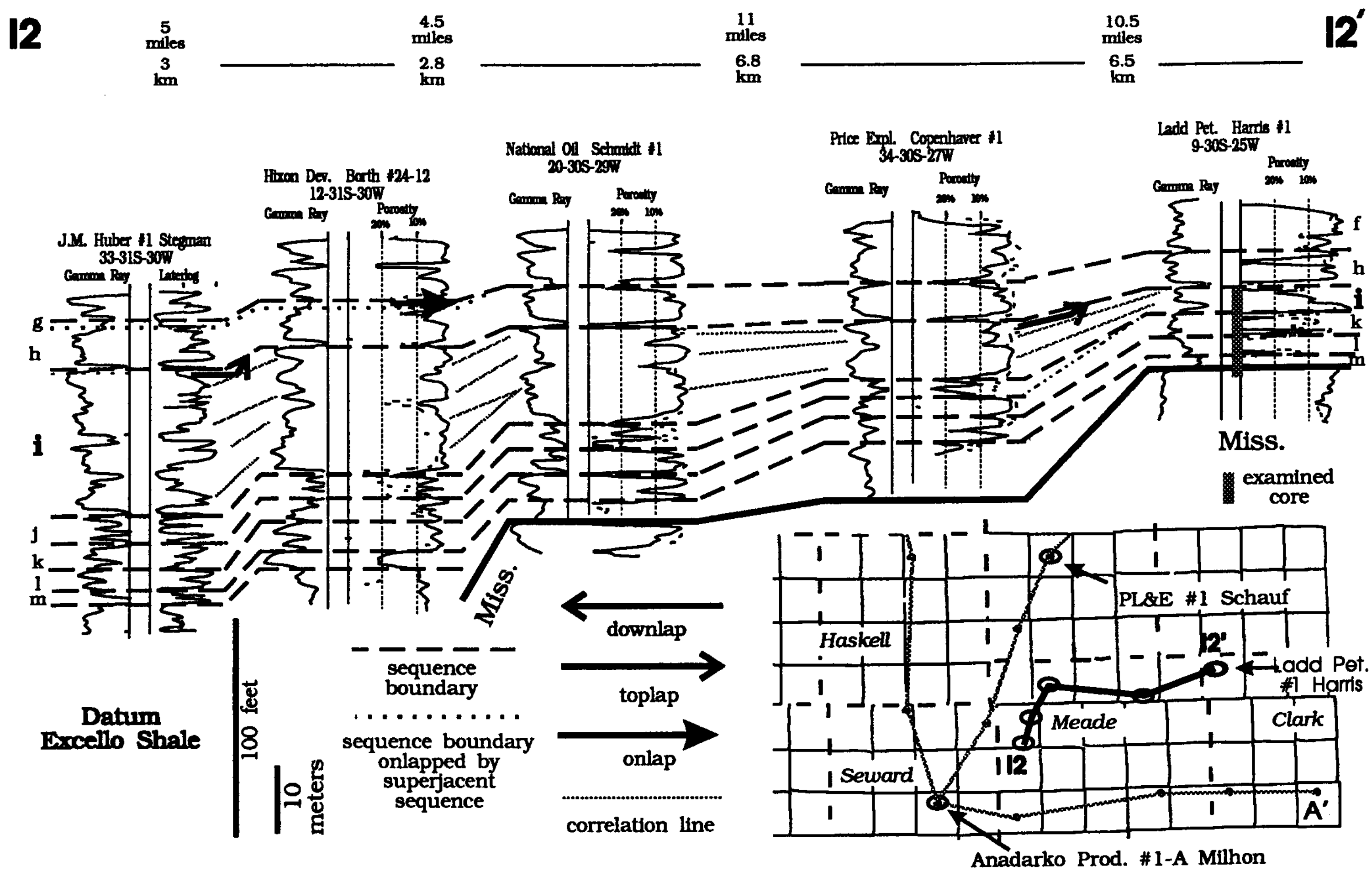

Fig. 35 Cross section I2-I2' displaying intrasequence i correlations from mid-shelf to proximal-shelf.

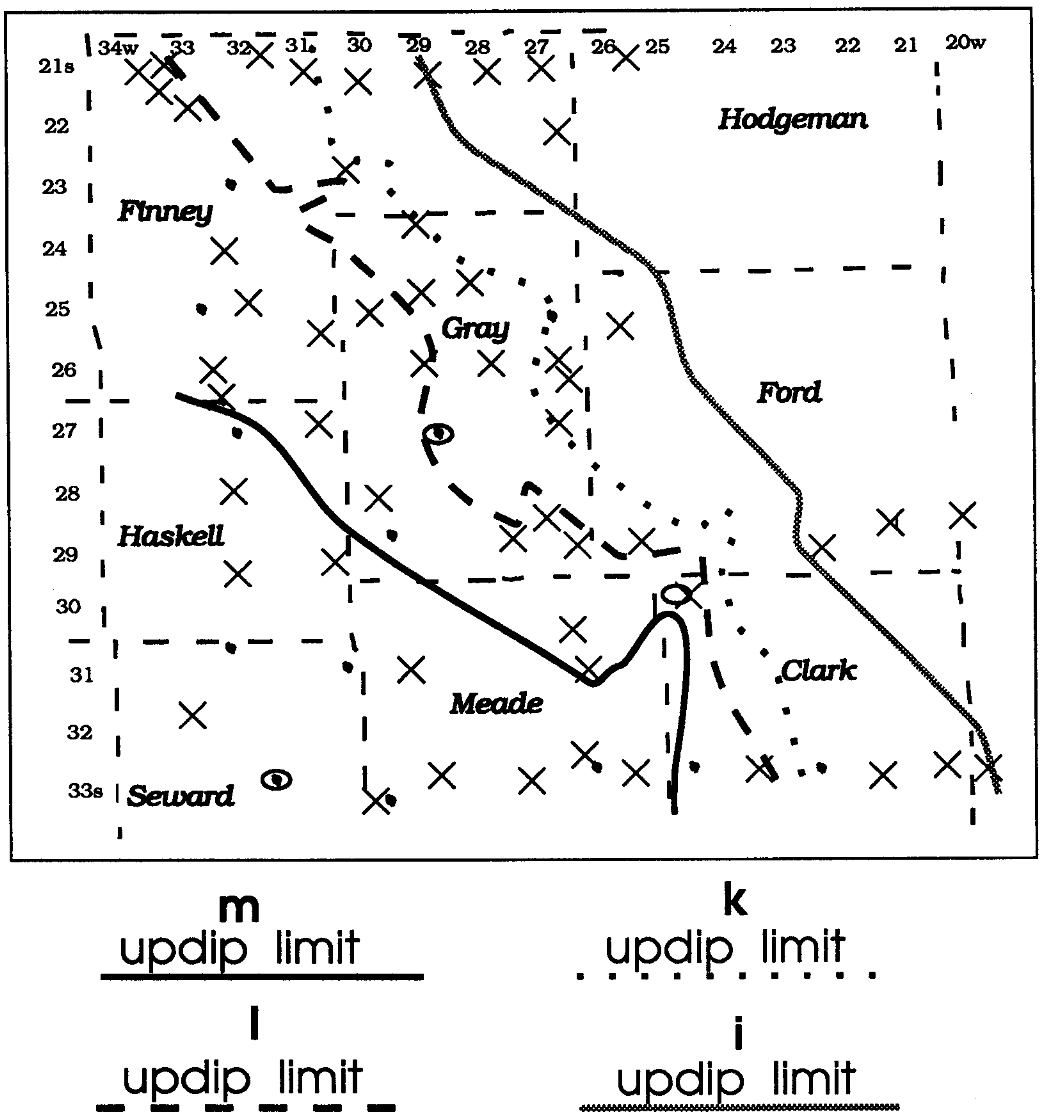

Fig. 36 Approximate updip limit of sequences that onlap pre-"Gray group" strata. Crosses mark control points; dots indicate well logs presented in this report.

depositional strike during deposition. This figure also displays the backstepping nature of the "Gray group" onto the Central Kansas uplift.

Figure 37 displays the up dip extents of sequences that onlap subjacent sequences. The sculpted appearance of these subcrops probably is a result of two factors. 1) uncertainty in placing the exact subcrop limit from correlation of wireline logs and 2) the effect of the paleotopography.

Comparison of "Gray group" Depositional Sequences to Classical Kansas Cyclothems

Within each depositional setting, "Gray group" sequences display a repetitious and predictable suite of facies; consequently, sequences can be compared to cyclothems. "Gray group" depositional sequences differ from Missourian cyclothems as described by Heckel (1977, 1989; Fig. 38) depending on their geomorphic position during deposition (Fig. 33).

Lower-shelf sequences differ from Heckel cyclothems because they lack transgressive (middle) limestones and regressive (outside) shales. The base of each lower-shelf sequence is marked by a condensed section of radioactive black-shale equivalent to Heckel's core shale

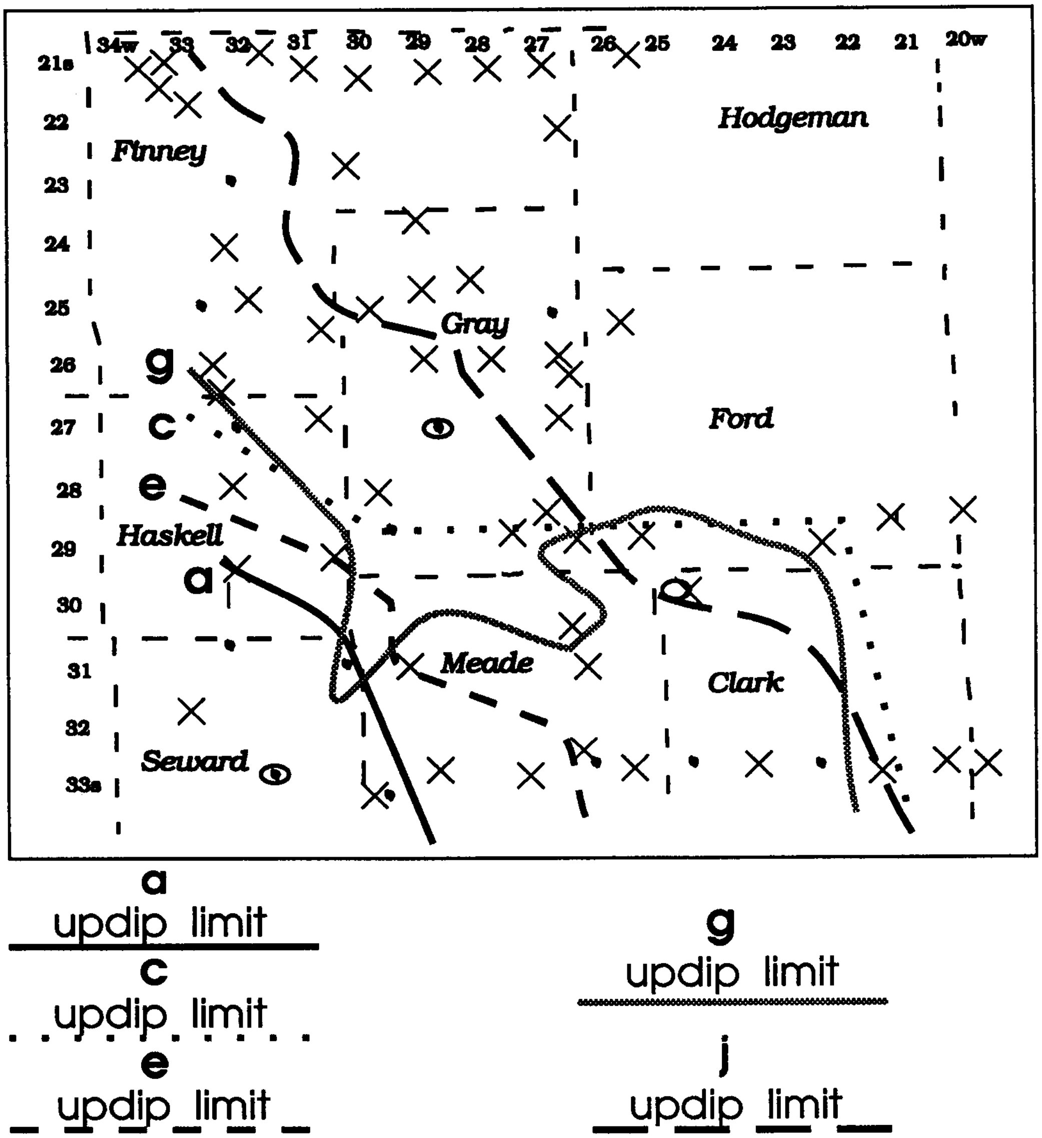

Fig. 37 Approximate updip limit of sequences that onlap subjacent sequences. Crosses indicate control points; dot indicate wells on regional cross-sections included in this report.

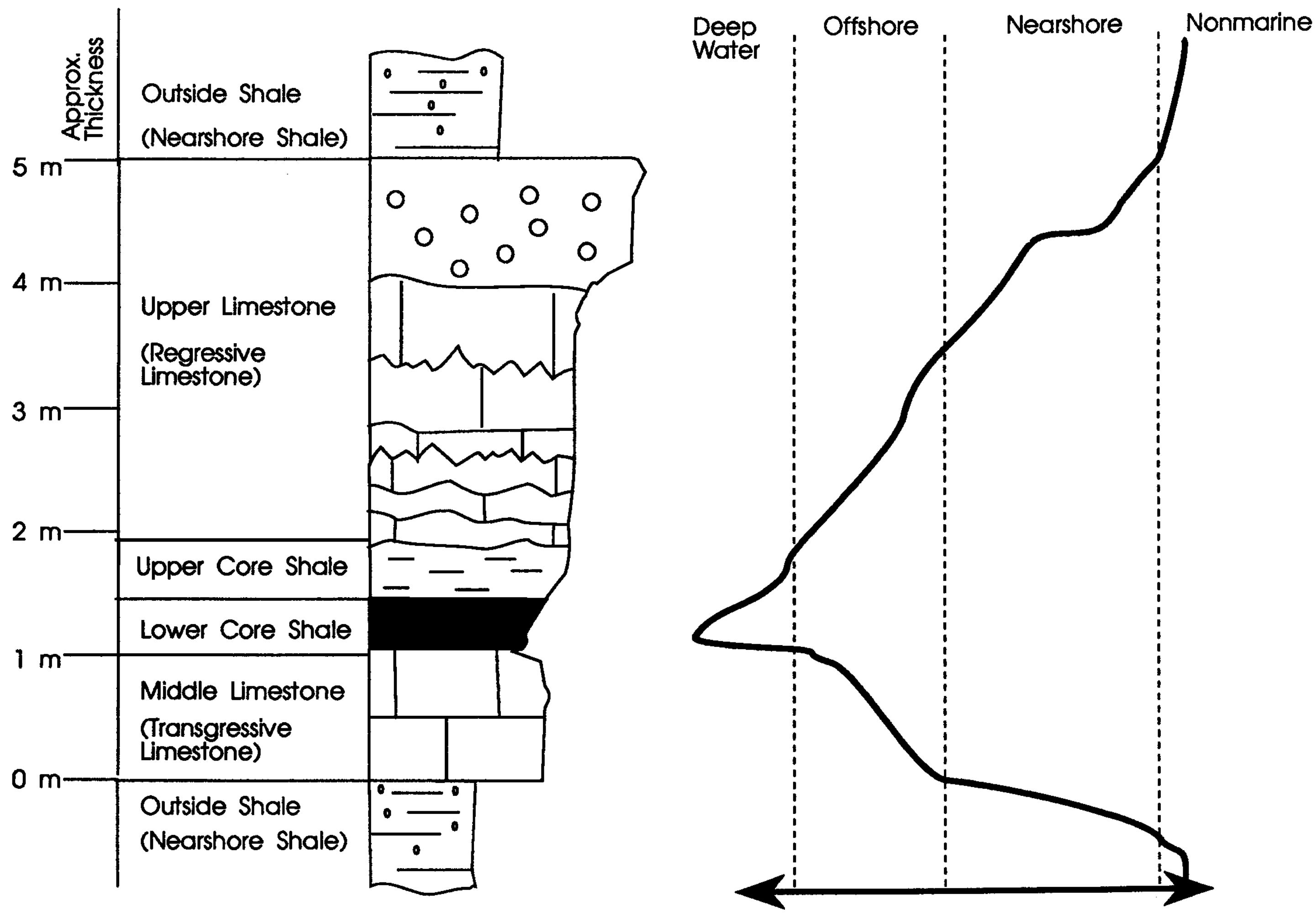

Fig. 38 Missourian-age Kansas Cyclothem (modified from Heckel, 1977, 1989)

(1977, 1989). The black shales grade vertically into a limestone that is equivalent to Heckel's regressive (upper) limestone. However, in lower-shelf sequences the regressive limestones may be conformably overlain by the black shale of the succeeding sequence; consequently lower-shelf sequences may lack both outside shales and transgressive limestones.

Mid-shelf sequences contain all the major components within the Heckel cyclothem, although transgressive limestones, core shales, and outside shale equivalents are extremely thin. Mid-shelf sequences contain a basal transgressive lag (generally less than 30 cm thick) equivalent to Heckel's transgressive limestone. The transgressive lag grades vertically into a condensed section (generally less than 60 cm thick) that is equivalent to Heckel's core shale. The shoaling-upward carbonates that overlie condensed sections in mid-shelf sequences are similar to Heckel's regressive limestone. The subaerial exposure surfaces that cap mid-shelf sequences are equivalent to Heckel's regressive (outside) shale.

Proximal-shelf sequences differ from cyclothems because they do not contain core shales. Transgressive (middle) limestones grade into overlying regressive (outside) limestones without development of an intervening core shale. The absence of core shale equivalents indicate that water depth was insufficient for development of a thermocline or to place the sediment-water interface below the photic zone, and reflects the lack of accommodation space available to proximal-shelf sequences. The turn-around point of the proximal-shelf sequence occurs within the carbonate. Proximal-shelf sequences are similar to cyclothems in that the regressive limestones may be overlain by thick soil profiles equivalent to Heckel's outside shales.

Depositional History of Lower Middle Pennsylvanian Strata in the Eastern Hugoton Embayment

Depositional sequences are the fundamental building blocks used to reconstruct the sea-level history that affected lower Middle Pennsylvanian deposition. The duration and driving forces behind development of depositional sequences are described first. This will be followed by discussion of larger-order changes in relative sea-level.

Fourth- to Fifth-Order Depositional Sequences

Biostratigraphic data are insufficient to resolve the duration of "Gray group" sequences. However, depositional sequences in the #1 Schauf core can be described as cycles that are similar in thickness to Missourian-age cyclothems described by Heckel (1977, 1986, 1991). Heckel (1986) estimated that the duration of "minor" Pennsylvanian cyclothems range from about 40,000 to 120,000 years and that major cyclothems may represent up to about 400,000 years of deposition. However, Klein (1990) points out that the estimated duration of the Pennsylvanian Period has been reduced by 45% since Heckel's early work and that cyclothem duration may be considerably less than Heckel estimated. Veevers and Powell (1987) estimated that glacioeustatically driven Pennsylvanian cycles averaged about 400,000 yrs in duration. Evans (1979) reported Quaternary glacioeustatic cycles averaged about 100,000 yrs in duration. Depositional sequences in the "Gray group" are interpreted to have been deposited in response to either fourth-order(0.1-1.0 m.y.; Goldhammer et al,, 1990) or fifth-order (0.01-0.1 m.y.; Goldhammer et al,, 1990) glacioeustatic cycles (Fig. 39).

Third-Order Sequence

Regional wireline-log correlations were employed to detect vertical changes in the distribution of facies, geometries, and stacking patterns of depositional

ORDER	TIME-SPAN	DESCRIBED BY
1st	100 million +	Pitman, 1978; Kominz, 1984
2nd	5-100 million	Vail et al., 1977; Haq et al., 1987
3rd	1-5 million	Vail et al., 1977; Haq et al., 1987
4th	0.1-1 million	Goldhammer et al., 1990
5th	0.01-0.1 million	Goldhammer et al., 1990

Fig. 39 Hierarchy of rock cycles.

sequences from the lower "Gray group" through lower Cherokee Group deposition. Evidence for the transgressive and regressive phases of the third-order relative sea-level cycle (1-5 m.y.; Vail, 1977) will presented first. Then the third-order relative sea-level cycle will be interpreted to represent a composite sequence that consists of transgressive, early-highstand, and late highstand sequence-sets.

Transgressive phase.- The vertical succession of facies in the Schauf core and regional spatial configurations of depositional sequences *m-f* as they onlap the Central Kansas uplift both indicate a third-order rise in sea-level occurred during deposition of "Gray group" strata.

In the Schauf core, each depositional sequence records one high-frequency relative sea-level cycle. Influence of the transgressive phase of a second, larger-order relative sea-level cycle is indicated by an overall increase in accommodation space vertically through the core.

Several observations in the Schauf core suggest an overall increase in accommodation space occurred during "Gray group" deposition: 1) exposure surfaces are common and closely spaced at the base of the "Gray group", but become more widely spaced up section (Fig. 9); 2) facies

LP-SH and SH, interpreted as having accumulated in the deepest water of all facies, are absent in sequences *k* and *l*; however, these facies become progressively thicker and better-developed in younger sequences; 3) proximal-shelf, lower-shoreface deposits are present only at the base of the "Gray group" in the top of sequence *l*; 4) in general, sequences thicken upward. The upward increase in thickness between exposure surfaces, increase in abundance and thickness of deeper water facies, and increase in thicknesses of sequences suggest an overall upward increase in accommodation space through the "Gray group". This overall increase in accommodation space is interpreted to represent the transgressive phase of a third-order rise in sea-level.

Regional cross-sections also indicate the presence of a third-order rise in relative sea-level during "Gray group" deposition. These cross-sections reveal that younger sequences overstep older sequences as the "Gray group" onlaps the Central Kansas uplift (e.g. Figs. 6,7,8 & 40).

The vertical succession of facies in the Schauf core and the regional geometries of "Gray group" sequences as they onlap the sub-Pennsylvanian unconformity surface depict the "Gray group" as a cyclic backstepping or retrogradational transgressive unit deposited during the

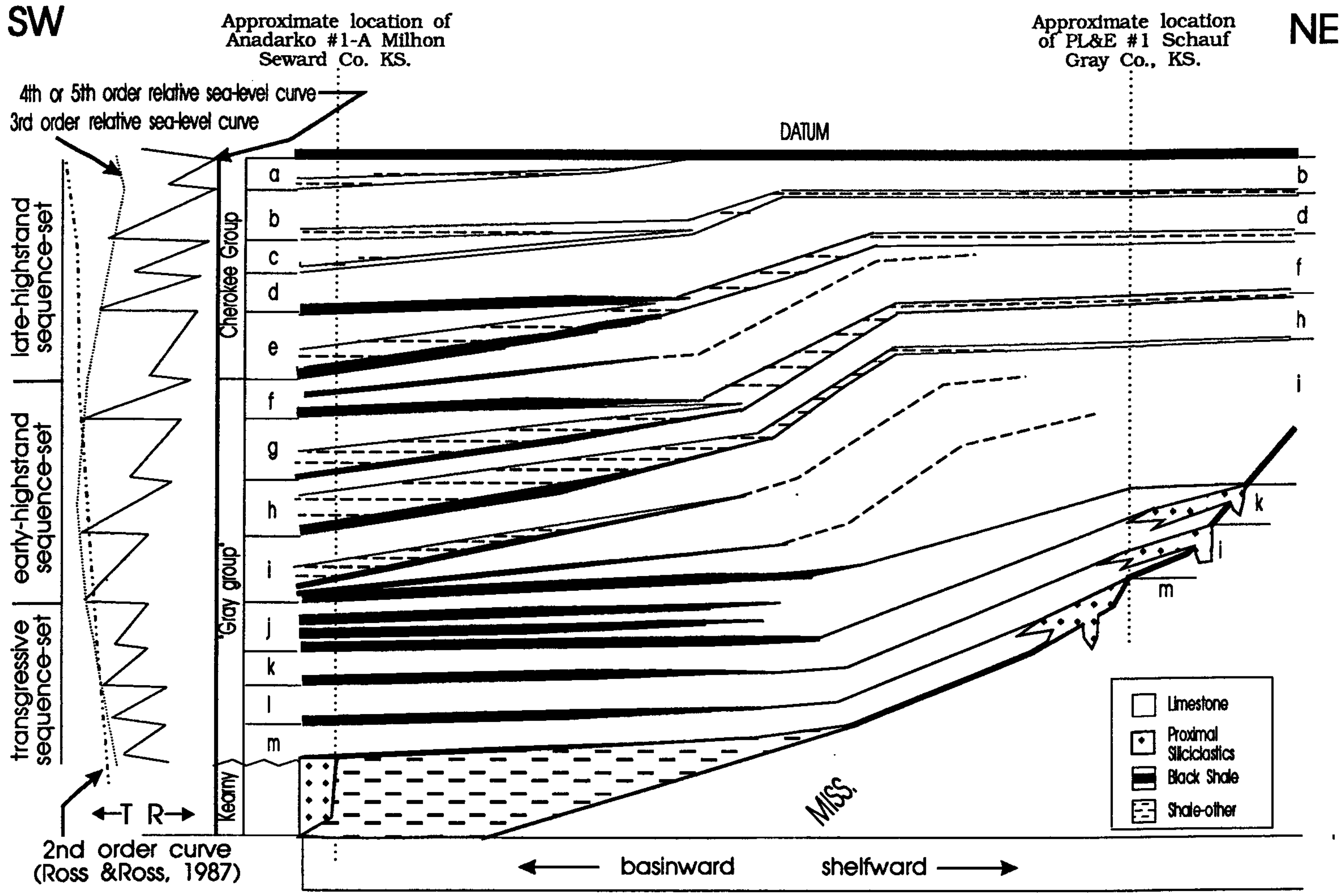

Fig. 40 Conceptual cross-section from distal Hugoton shelf northeastward through study area.

transgressive phase of a third-order relative sea-level cycle.

Regressive phase.- The wireline log of the Anadarko Production Co. Milhon #1-A (Figs. 6,7 & 8) illustrates changes in the distribution of facies that reflect a third-order fall in relative sea-level from upper "Gray group" through lower Cherokee Group deposition. In the Milhon #1-A, lower Cherokee Group sequences *a* through *c* lack the thick "hot" shales that underlie sequences *f-m*. Sequences *a* through *c* are also thicker and contain a greater percentage of limestone than sequences *f-m*. Wireline-log characteristics of sequences *a,b*, and *c*, in the Milhon #1-A, resemble the wireline-log characteristics of mid-shelf sequences *f,h*, and *i* in the #1 Schuaf (Fig. 6). Sequences *d* and *e* have wireline-log characteristics that are transitional between sequences *f-m* and sequences *a* through *c* (Fig. 6). In the #1-A Milhon, the vertical decrease in black shales and concomitant increase in limestone indicate that mid-shelf facies prograded basinward from upper "Gray group" through lower Cherokee Group deposition, and reflect a third-order regression.

Regional cross-sections also reveal the presence of a third-order regression. Sequences *a,c,e* and *g* onlap subjacent sequences and are restricted to distal portions of the eastern Hugoton shelf (Figs. 6,7,8 & 40). Younger sequences thicken basinward of older sequences and also indicate a decrease in accommodation space from "Gray group" through lower Cherokee Group deposition (Fig. 40). The decreases in accommodation space on the shelf and progradation of mid-shelf facies basinward from "Gray" through lower Cherokee Group deposition are interpreted to represent a third-order regression (Figs. 39 & 40).

Third-order composite sequence

The third-order relative sea-level cycle is interpreted to represent a composite sequence (Mitchum and Van Wagoner, 1991) and is subdivided into three sequence sets. Each sequence set contains four or five fourth- to fifth-order depositional sequences. Transgressive, early highstand, and late highstand sequence-sets are identified based upon similarities in the geometries, stacking patterns, and facies distributions within the fourth- to fifth-order depositional sequences that comprise them.

Transgressive sequence-set. Transgressive sequence-sets are deposited during maximum rates of a third-order relative sea-level rise (Mitchum and Van Wagoner, 1991). Lower "Gray group" sequences *m* through *k* are interpreted to comprise a transgressive sequence-set for three reasons: 1) younger sequences successively overstep older sequences toward the shelf (Figs. 6,7,8 & 40); 2) younger sequences contain deeper-water facies than older sequences (Fig. 9), and 3) none of the sequences thicken more than two fold from the lower-shelf into the mid-shelf (Figs. 6,7,8 and 40). Related to this lack of thickening is the observation that depositional sequences in the transgressive sequence-set do not display well-developed internal toplapping and downlapping stratal terminations. The lack of both thickness changes and well-developed toplapping and downlapping stratal terminations separate sequences in the transgressive sequence-set from those in the early-highstand sequence-set.

The lack of thickness change in sequences *m-j*, compared to sequences *i-f* may reflect a lack of well-developed aggradational or progradational parasequences within these sequences, and is consistent with observations of the Schauf core. It is plausible that during maximum rates of a third-order sea-level rise, high-frequency, low-amplitude perturbations in relative sea-level are damped out and not well preserved in the rock record.

Incised-valley-fill estuarine sandstones are best preserved in sequences within the transgressive sequence-set and will be discussed in more detail in chapters 5 and 6.

Early highstand sequence-set.- Upper "Gray group" sequences *i-f* also successively overstep older sequences and onlap the sub-Pennsylvanian unconformity surface, with the exception of sequence *g* which onlaps sequence *h*. However, unlike sequences *j-m*, sequences *i-f* increase in thickness up to five fold from lower-shelf to mid-shelf settings. Depositional sequences *i-f* display internal toplapping and downlapping stratal terminations suggestive of the presence of thick progradational to aggradational parasequences (Figs. 34 and 35). The development of aggradational to progradational parasequence sets suggest deposition during the early part of a highstand-system-tract (Van Wagoner, 1990).

The early highstand sequence-set is deposited when the third-order rate of sea-level rise slows, stops, and then falls slowly. Third-order rates of sea-level change are minimal in the early-highstand sequence-set; consequently, it is probable that very high-frequency, low-amplitude, relative sea-level fluctuations may be preserved in the rock record with greater fidelity than is possible during deposition of other sequence-sets.

Late highstand sequence-set.- Sequences *e-a*, in the lower Cherokee Group, thicken basinward of older sequences and display a distinct progradational pattern (Figs. 6,7,8 & 40). Half of the lower Cherokee Group sequences onlap subjacent sequences and are restricted to distal portions of the eastern Hugoton shelf. As stated earlier, facies changes in sequences *a-e* in the Milhon #1-A also indicated a fall in relative sea-level. These traits indicate that the Lower Cherokee Group sequences were deposited during a third-order fall in relative sea-level and are suggestive of deposition within a late highstand to lowstand sequence-set.

Second-Order Sequence

Eustatic sea-level curves presented by Ross and Ross (1987) indicate a second-order sea-level rise (approximately 25 m.y.) associated with the beginning of the Absaroka cratonic sequence may have also affected deposition during the "Gray group" (Fig. 40). The updip terminus of upper "Gray group" sequences has not been determined yet; however, it is possible that some of the late-highstand sequences may overstep older sequences during an increase in the rate of second-order sea-level rise.

CHAPTER FOUR

STEWART POOL: AN EXAMPLE OF A RESERVOIR SANDSTONE WITHIN THE "GRAY GROUP"

Introduction

The Stewart Pool is located in Finney County, Kansas, along the eastern Hugoton shelf (Fig. 1). The field has produced about three million barrels of oil since discovery in 1967. Most of this production has come from 47 wells that produce from sequence *1* sandstones up to 21 m thick (Fig. 41). Sandstone producers lie within a paleovalley that is incised up to 15 m into underlying Mississippian carbonates (Figs. 42,43, & 44). In map view the oil-productive portion of the incised valley forms a sinuous fairway about 4.3 km long and 0.15 km wide. Seven wells produce from Mississippian oolite on erosional highs surrounding the incised valley (Fig. 41).

Sequence *1* siliciclastics in the Stewart Pool are interpreted to have been deposited in an estuary. According to Emery and Stevenson (1957), estuaries are bodies of water that occupy drowned stream mouths, usually lie perpendicular to the coast line, and are surrounded on three sides by land masses. The best evidence for estuarine deposition lies in the spatial

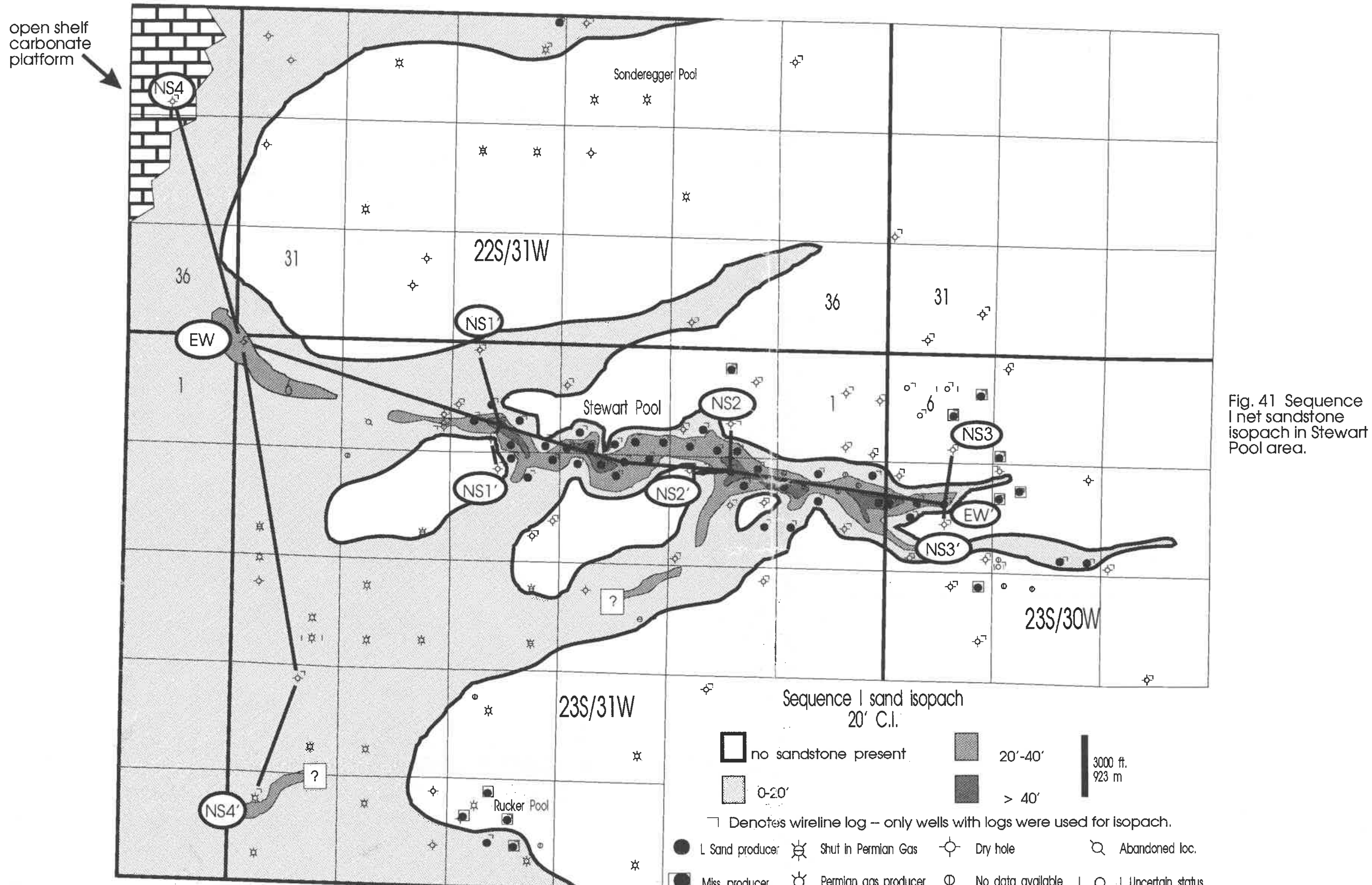

Fig. 41 Sequence I net sandstone isopach in Stewart Pool area.

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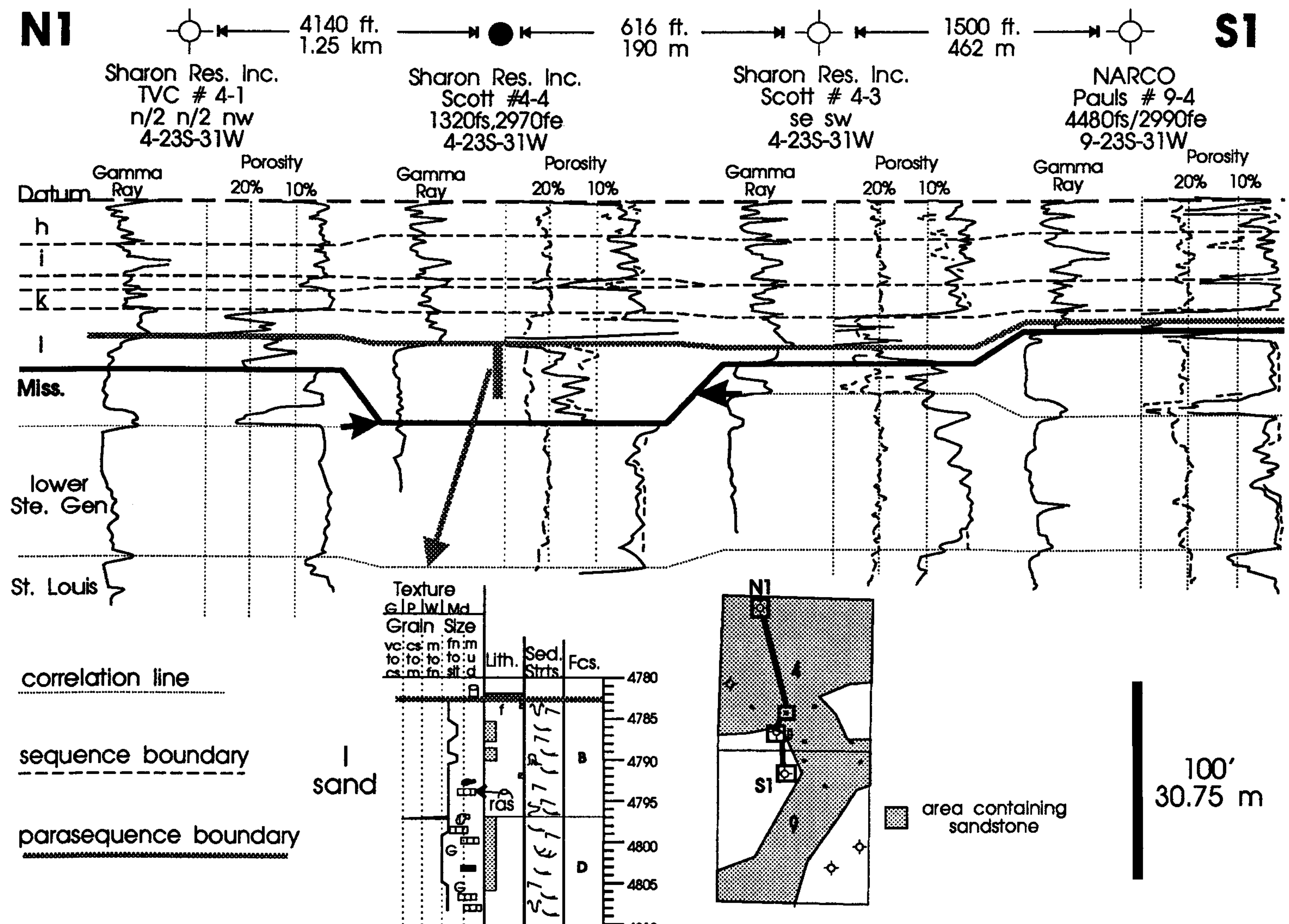

Fig. 42 North-South cross-section through western portion of Stewart Pool. Core key Fig. 49.

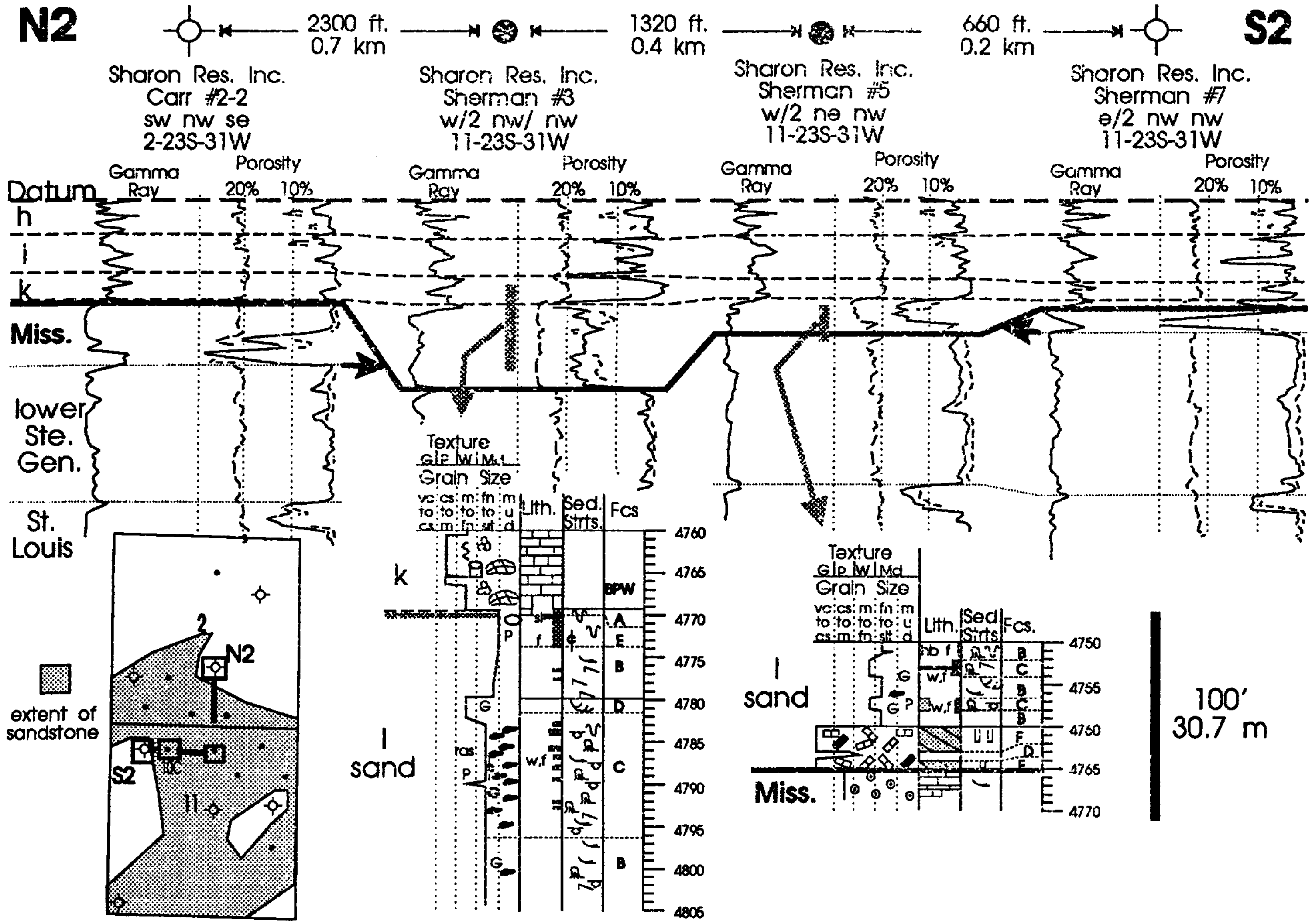

Fig. 43 North-south cross section NS2 through center of Stewart Pool. Core key Fig. 49.

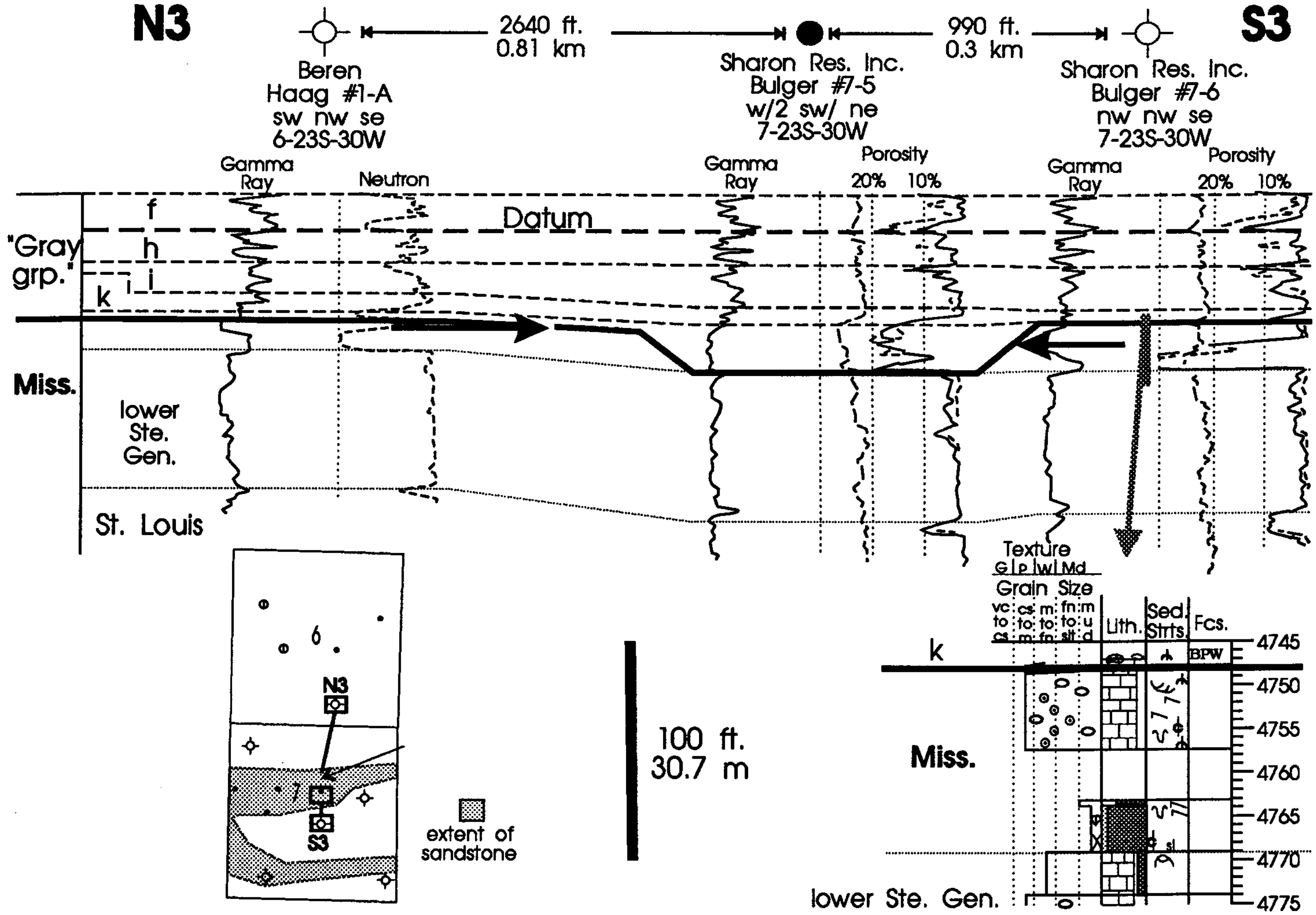

Fig. 44 North-south cross section NS3 through eastern Stewart Pool. Key Fig. 49.

configuration of sequence *1* siliciclastics and their lateral facies transition into contemporaneous carbonates.

Stewart Pool lithofacies are also suggestive of estuarine deposition, although no diagnostic evidence was detectable in core. Sediments that characterize estuaries are widely variable depending on a complex interplay between waves, tides, fluvial discharge, source areas, climate, and paleotopography. Clifton (1982) states that "probably no diagnostic physical criterion exists for estuarine deposition." However, one of the criterion used to identify many ancient estuaries is evidence of tidal deposition (Clifton, 1982). Diagnostic tidal indicators, like tidal bundling, neap-spring cyclicity and brackish water ichnofacies are not present in Stewart Pool cores. However, the presence of sedimentary structures suggestive of tidal deposition, presence of both marine and terrestrial constituents, and the vertical succession of lithofacies in Stewart Pool cores all indicate sequence *1* siliciclastics were deposited in an estuary.

Methods

Townships 22 and 23S, ranges 30 and 31W have been mapped in detail from over two hundred wireline logs and scout tickets. Additionally, six cores and twenty thin sections were examined in the Stewart Pool.

Analysis of the Stewart Pool is presented in five parts. The first part uses regional wireline log cross-sections to illustrate the regional geologic setting and stratigraphy of the Stewart Pool. This section also details the correlation of sequence *1* shelf carbonates into contemporaneous oil-productive siliciclastics.

The second part of this investigation uses wireline-log cross-sections and isopach maps to define the estuarine paleogeomorphology of the Stewart Pool during deposition of sequence *1* sandstones.

The third part of this investigation uses closely spaced wireline logs and cores to describe and interpret lithofacies in the Stewart Pool. Tidal, marine, and fluvial influences upon deposition of these lithofacies are discussed and compared to sediments found in modern estuaries.

The fourth section compares the Stewart estuary and its assemblage of lithofacies to modern tripartite models of estuarine deposition.

The fifth and final part of this investigation divides sequence *l* siliciclastics into two parasequences and reconstructs the complex depositional history of the Stewart Pool estuary. This section also relates estuarine deposition with correlative carbonate deposition.

Geologic and Stratigraphic Setting

Cross-section ST-ST′ (Fig. 45) runs from regional cross-section E-E′ (Fig. 8) northeastward into central Finney County. It displays the regional correlation of "Gray group" sequences from southwestern Finney County into the Stewart Pool.

The onlap of the Kearny Formation and "Gray group" sequence *m* onto the sub-Pennsylvanian unconformity surface southwest of the Stewart Pool and the thinning of "Gray group" sequences *j* and *k* to the northeast (Fig. 45) reflect the northeast-southwest orientation of paleodepositional dip. Upper "Gray group" sequences (*f*-*i*) remain relatively unchanged in thickness from central Finney County into the Stewart Pool area and indicate that subregional paleotopography was largely compensated for by the time sequence *i* was deposited.

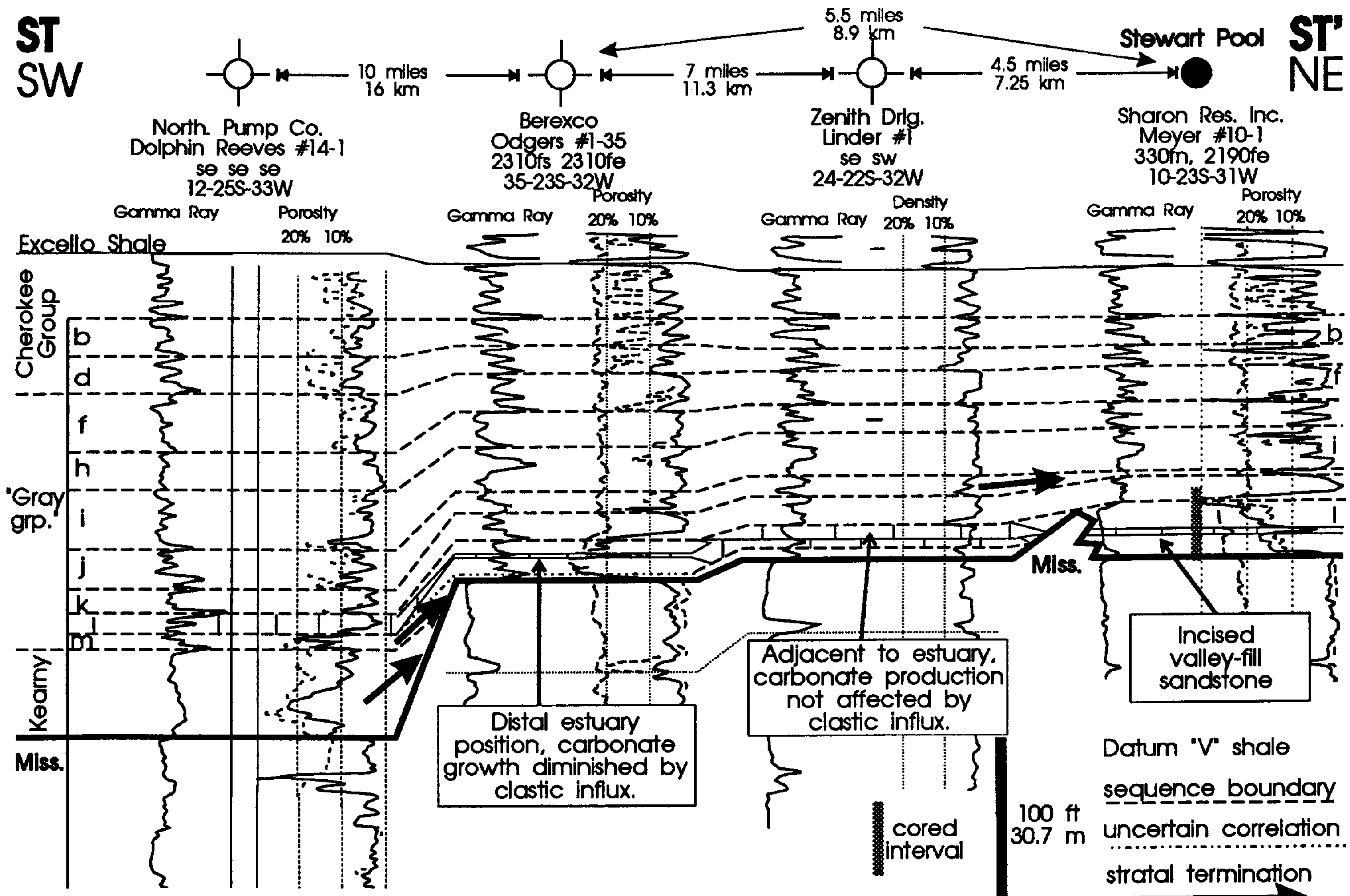

Fig. 45 Regional cross section ST-ST', from southwestern Finney Co. northeast to Stewart Pool. See Fig. 2 for location of cross section.

Regional Distribution of Sequence 1 Lithotypes

The distribution of sequence *1* lithotypes can be discerned from wireline-log cross-sections ST (Fig. 45), NS4 (Fig. 46), and EW1 (Fig. 47). These cross-sections show the gradational change of sequence *1* facies from shelf carbonates into contemporaneous siliciclastics.

Cross section ST (Fig. 45) shows the subregional variability in sequence *1* lithotypes that reflects the complex interplay between carbonate-shelf deposition and siliciclastic influx. The Berexco Odgers #1-35, located about 2.5 km southwest of the Stewart Pool, does not appear to display any significant incision into the Mississippian; although well control is sparse in this area. In the #1-35 Odgers, sequence *1* contains a thin carbonate (92 cm thick) imbedded in the middle of about 6 m of shaly siliciclastics. About 4.3 km north of the #1-35 Odgers, wireline logs indicate that sequence *1* strata in the #1 Linder consists of about 6 m of limestone with no siliciclastics. This suggests that carbonate production was adversely affected by terrigenous input in the #1-35 Odgers while open marine conditions prevailed in the #1 Linder. The Stewart Pool lies about 2.5 km northeast of the #1-35 Odgers and about 2 km southeast of the #1 Linder; consequently, the trend of siliciclastic

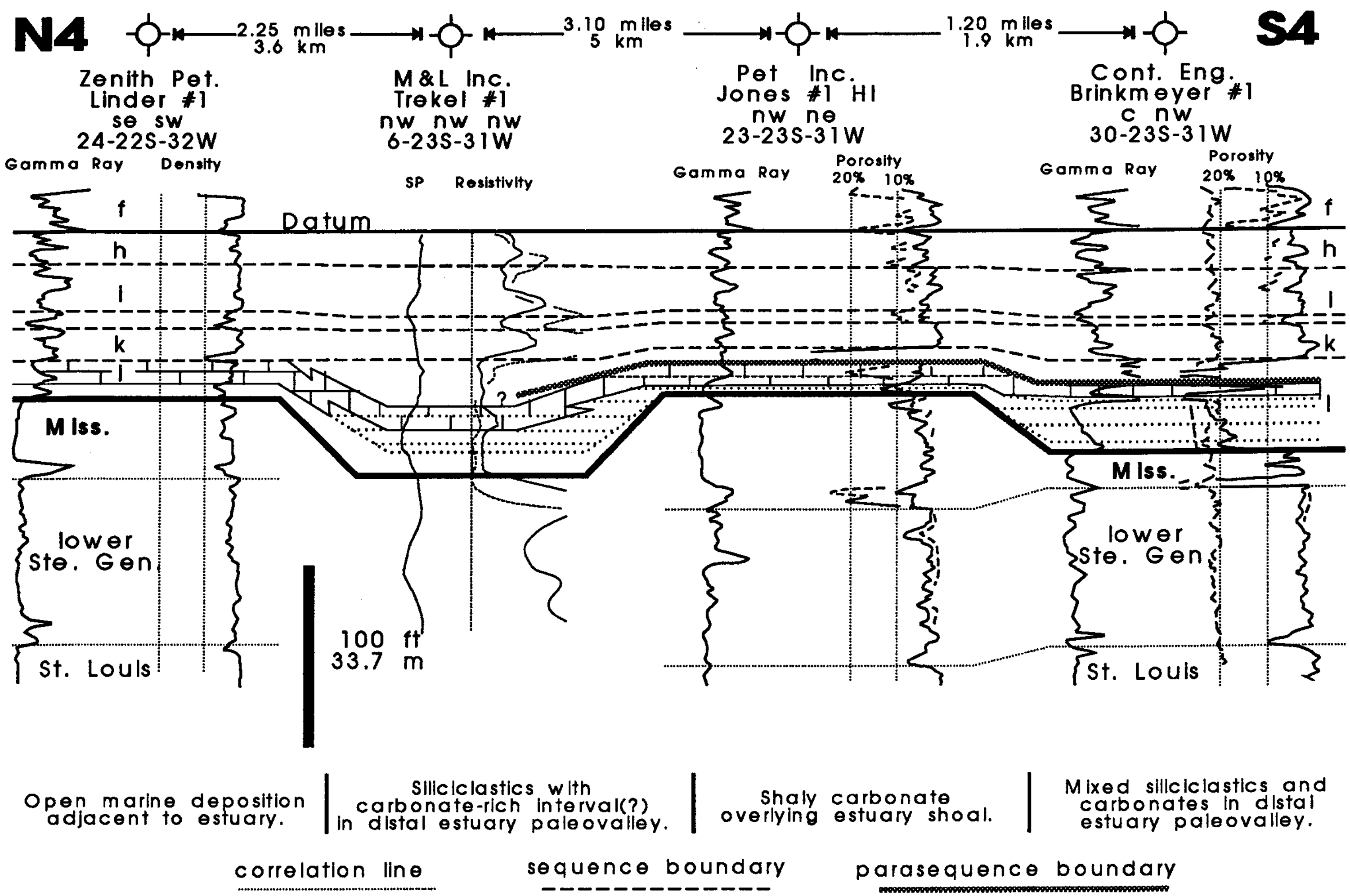

Fig. 46 North-south cross section several miles west (seaward) of the Stewart Pool. See Fig. 41 for location.

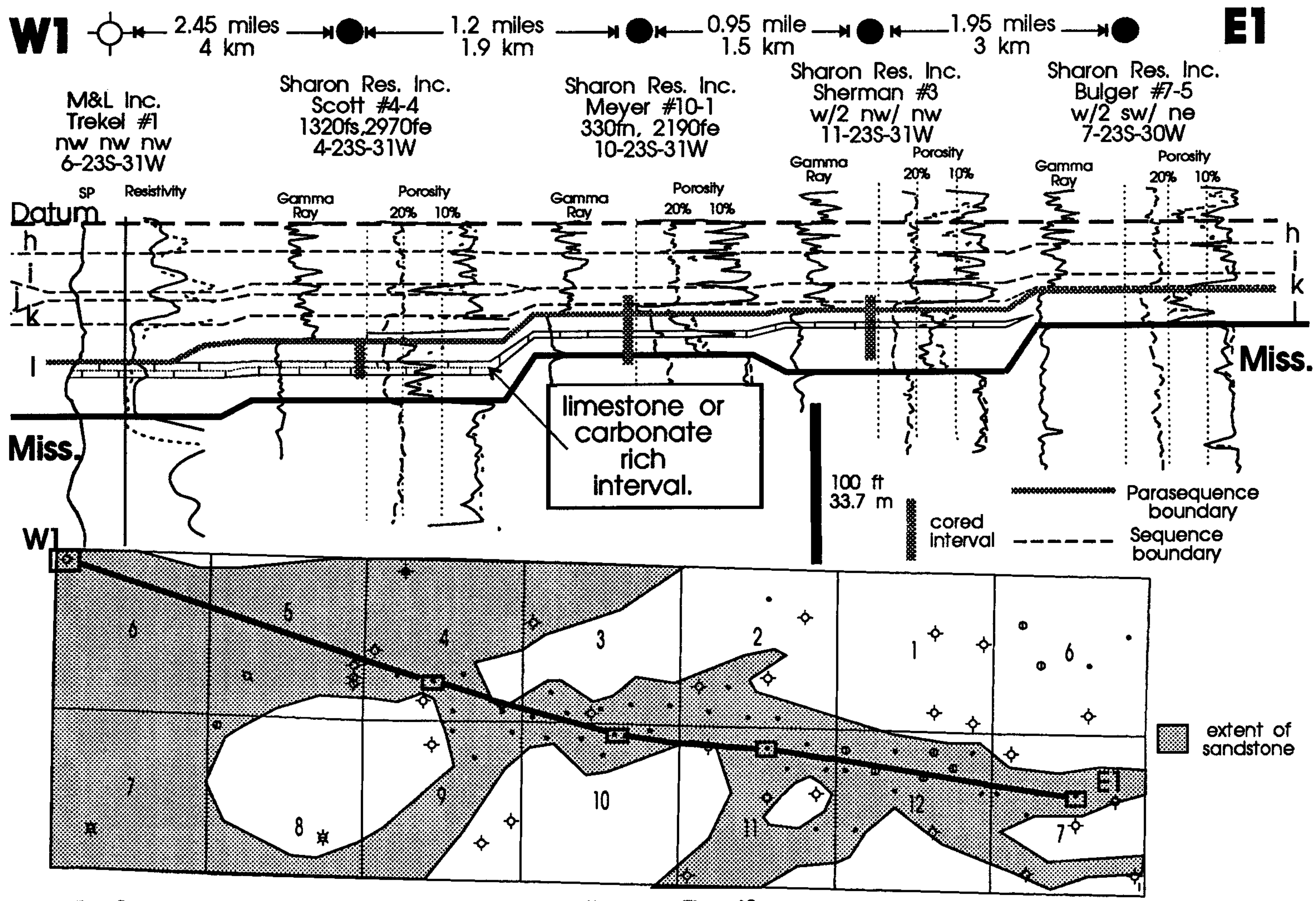

Fig. 47 Cross section EW1. Wireline Log explantion on Fig. 49.

influx that retarded carbonate production in the #1-35 Odgers is NE-SW and parallel to paleodepositional dip.

Cross section NS4 (Fig. 46) shows that the 6 m of sequence *1* limestones in the #1 Linder grade southward over 1.4 km into about 17 m of siliciclastics in the M&L Terkel #1. Cross-sections NS4 and EW1 (Fig. 46 & 47) and sequence *1* isopach maps (Fig. 41 & 48) indicate that the #1 Terkel lies within the same incised valley that houses the Stewart Pool. However, wireline logs in the #1 Terkel do not indicate the presence of any reservoir-quality sandstone. Wireline logs also reveal a 3 m thick interval of slightly higher resistivity in the middle of the siliciclastics that suggests the presence of a carbonate-rich interval. Despite the location of the #1 Terkel within the incised valley, the valley-fill succession in this well appears to be transitional between reservoir-quality siliciclastics landward, in the Stewart Pool, and adjacent shelf carbonates.

About 1.85 km further south of the Terkel #1, the Petroleum Inc. #1 Jones, like the #1 Linder, also contains about 6 m of *1* strata. Neutron-density-wireline logs in the #1 Jones indicate *1* strata consist of about 1 m of basal sandstone overlain by about 4.3 m of shaly carbonate. Isopach maps and cross section NS4 suggest that the #1 Jones is sitting on a localized high on the

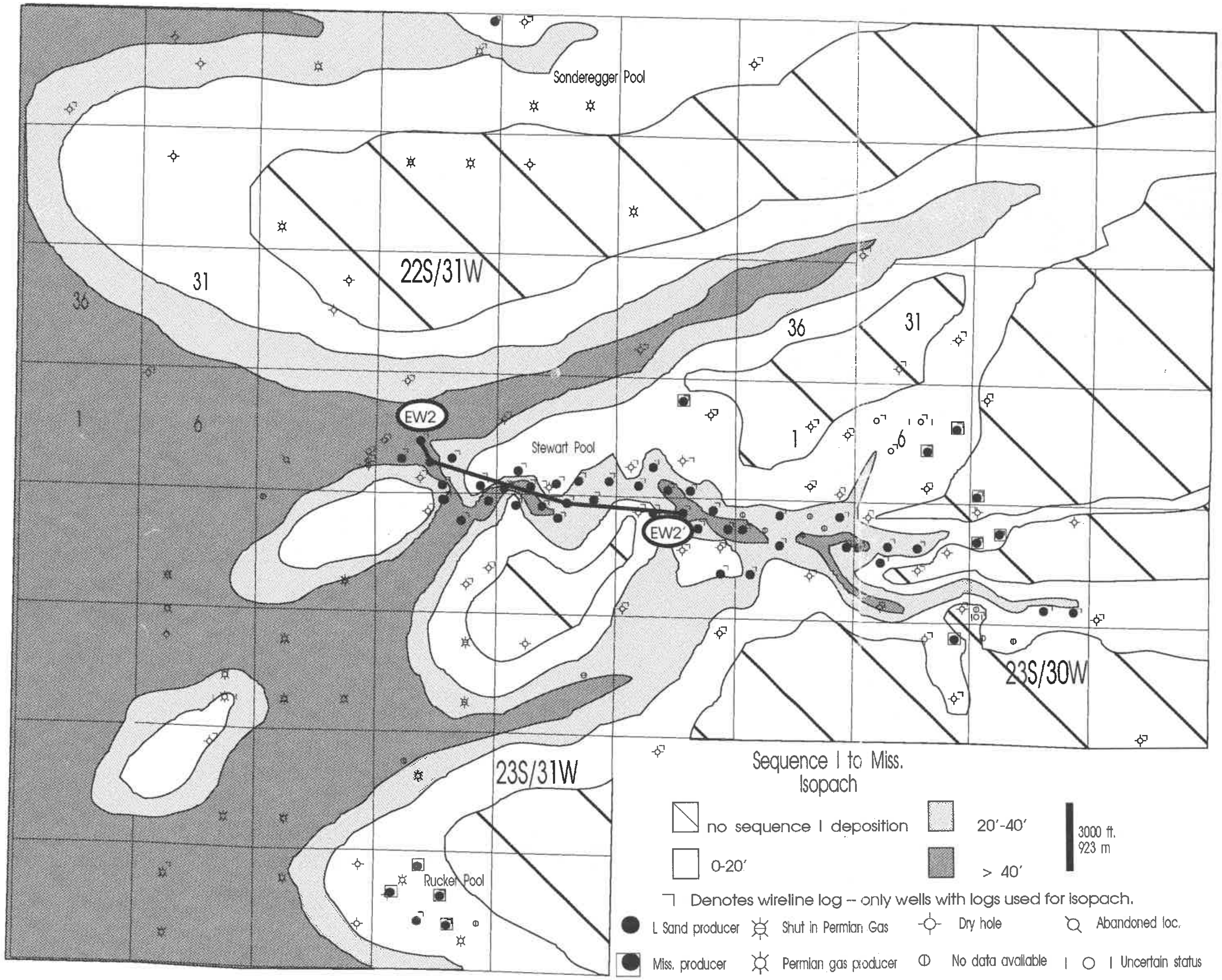

Fig. 48 Sequence I isopach map in Stewart Pool area.

unconformity surface. The facies transition between the #1 Terkel and the #1 Jones is similar to the transition between the #1 Linder and #1 Terkel. In both transitions siliciclastic dominant lithotypes in the incised valley grade laterally into contemporaneous carbonate-dominant lithotypes marginal to the incised valley.

A little over 0.62 km further south of the Jones #1, *1* strata thicken again to over 18 m in the Brinkmeyer #1. The bottom half of the Brinkmeyer #1 contains about 6 m of coarsening upward sandstone that is overlain by a 1.25 m thick carbonate.

The carbonate-rich interval in the #1 Terkel can be traced landward, on wireline logs (Fig. 47), to the Meyer #10-1 core (Fig. 49) where core data indicates it is a sandy bioclastic packstone and grainstone layer 80 cm thick. The carbonate in the Meyer #10-1 lies gradationally within the middle of the sandstones that fill most of the incised-valley at the Stewart Pool. A bioclast-rich sandstone, possibly correlative with carbonate in the Meyer #10-1, is about 60 cm thick in the Sherman #3; however, wireline logs do not detect any significant carbonate further landward of the Meyer #10-1. These correlations establish that a tongue of *1* sequence carbonate gradationally passes landward into the middle of the siliciclastic facies in the Stewart Pool

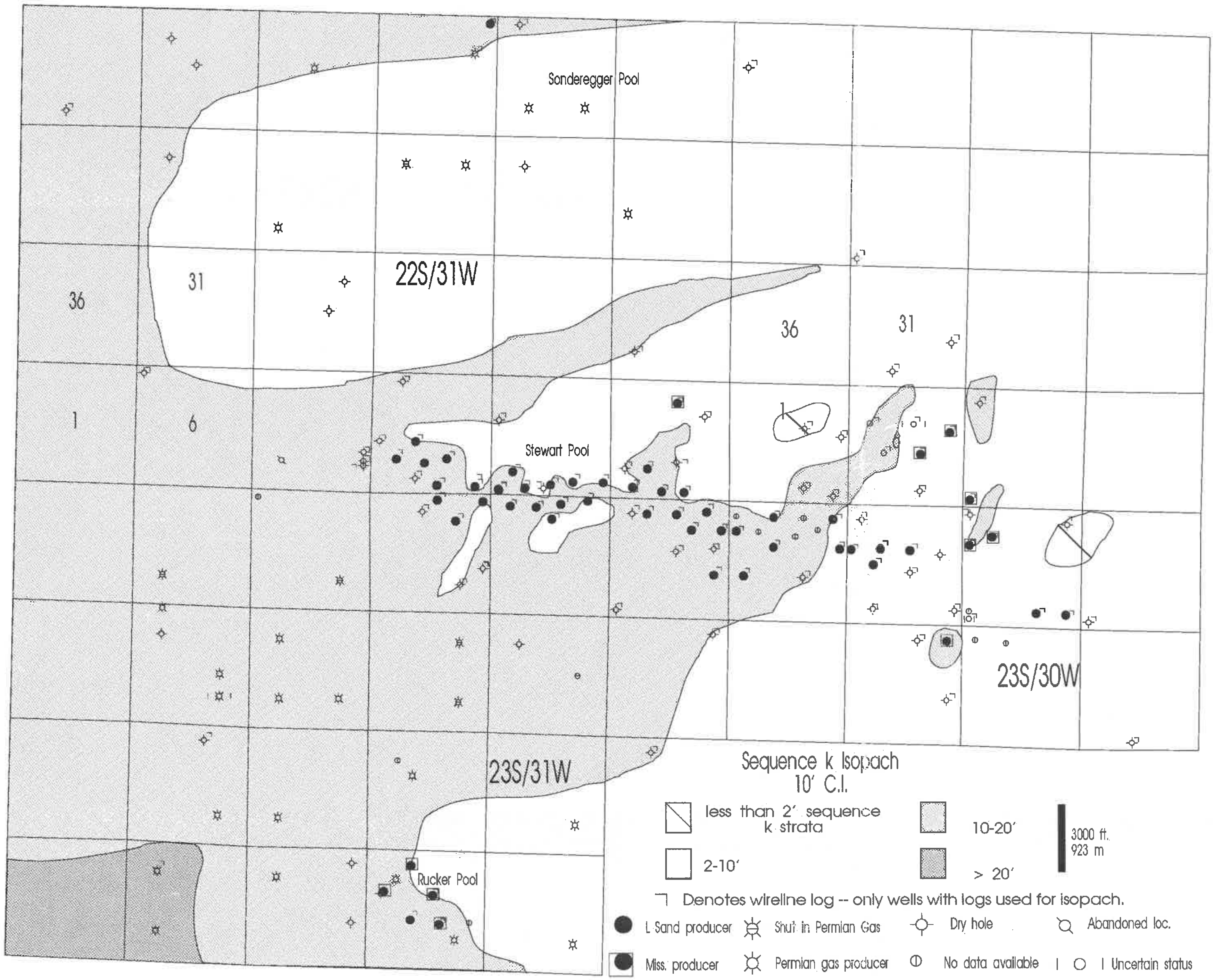

Fig. 49 Sequence k isopach map in Stewart Pool area.

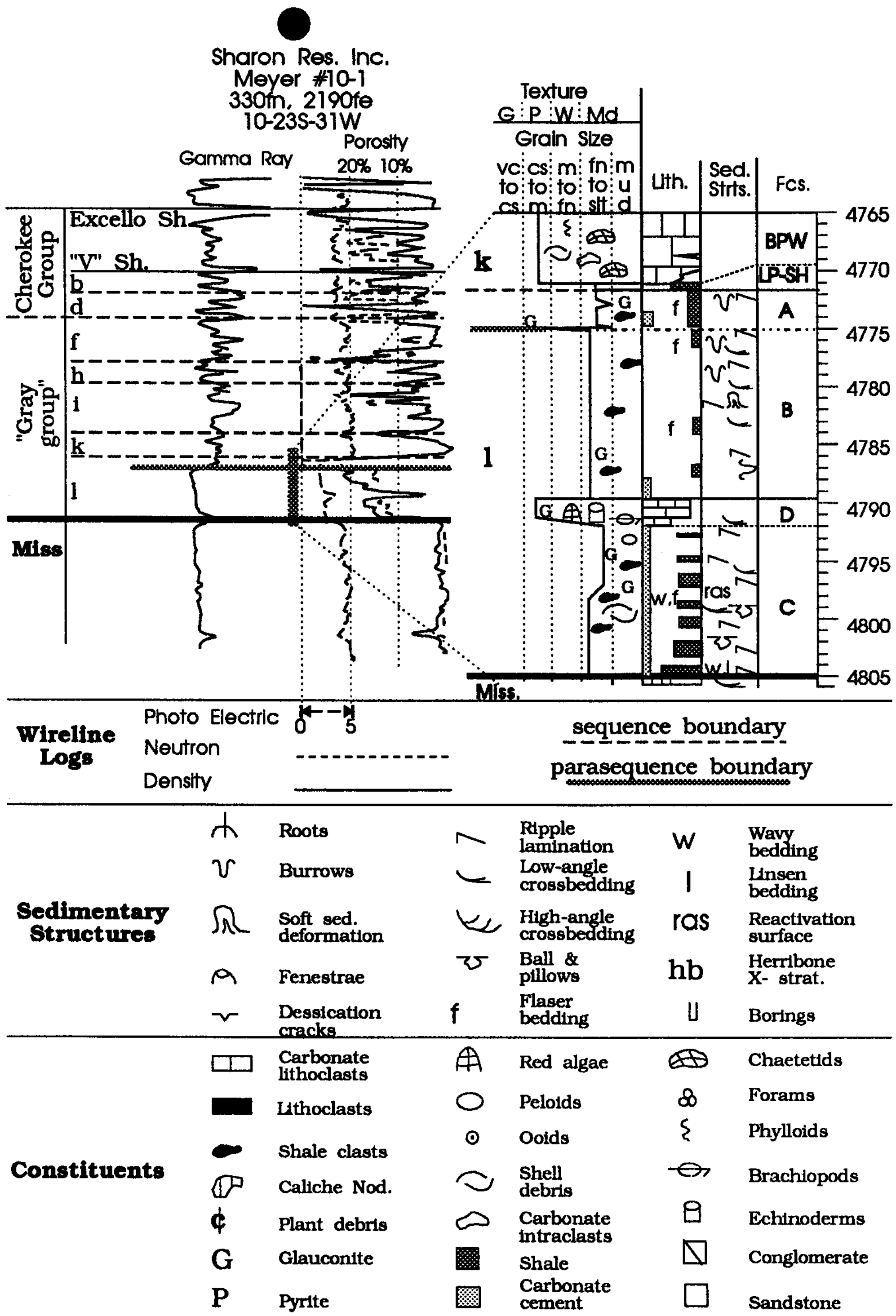

Fig. 49 Type section for Stewart Pool and key for core descriptions.

and establishes that the incised-valley-fill succession was connected to an open marine environment to the west.

Geomorphic Setting of the Stewart Pool Area during "Gray group" Deposition

Isopach maps and wireline-log cross-sections illustrate the paleogeomorphology of the Stewart Pool during deposition of sequences *k* and *l*. Comparison of the isopach maps from the base and top of sequence *k* (Fig.s 48 and 50) indicate that sequence *k* strata overstep sequence *l* strata in the Stewart Pool area. Locally, sequence *k* carbonates thin and onlap pre-Gray group structural highs in the eastern third of the study area (Fig. 50). This indicates that not all local paleotopography in the Stewart Pool area was compensated for by the end *k* deposition. However, comparison of the two isopach maps also reveals that the incised valleys in the Stewart Pool area were largely filled by *l* strata (Figs. 41,48 & 50).

Isopach maps from the base of sequence *k* to the Mississippian reveal the depositional topography upon which sequence *l* strata were deposited (Fig. 47). This isopach displays three morphologic characteristics that the Stewart Pool area have in common with modern estuaries: 1) funnel-shaped geometry, 2) presence of incised valleys or drowned streams within the funnel, and 3) presence of localized estuary shoals or islands of older strata.

An area containing ten or more feet (3 m) of sequence *1* strata ranges from being nearly 3.75 km wide and filled with up seventy feet (21.5 m) of pre-*k* strata in the western third of T23S R31W, to less than 0.15 km wide and filled with 15 feet (4.5 m) of pre-*k* strata in section 7 of T23S R30W. The configuration of the ten-foot (3 m) isopach reveals the presence of a broad, funnel-shaped low in the Mississippian. This is a common shape in modern estuaries. Bathymetric maps of the Gironde estuary of central France (Fig. 51) display a change in bathymetry from over twenty meters in the estuary mouth to less than five meters in upper-estuary channels.

The sequence *1* isopach map also reveals that two relatively narrow areas where *1* strata are unusually thick (less than a third of a km in wide and greater than 15 m thick) are included within the funnel-shaped low. These narrow "thicks" merge in section 4 T22S R31W (Fig. 48). Cross sections NS1 and NS2 reveal that Mississippian strata have been truncated within these thicks and strongly suggests that they are pre-Pennsylvanian valleys that have been incised into

Morphology of Gironde estuary, France.

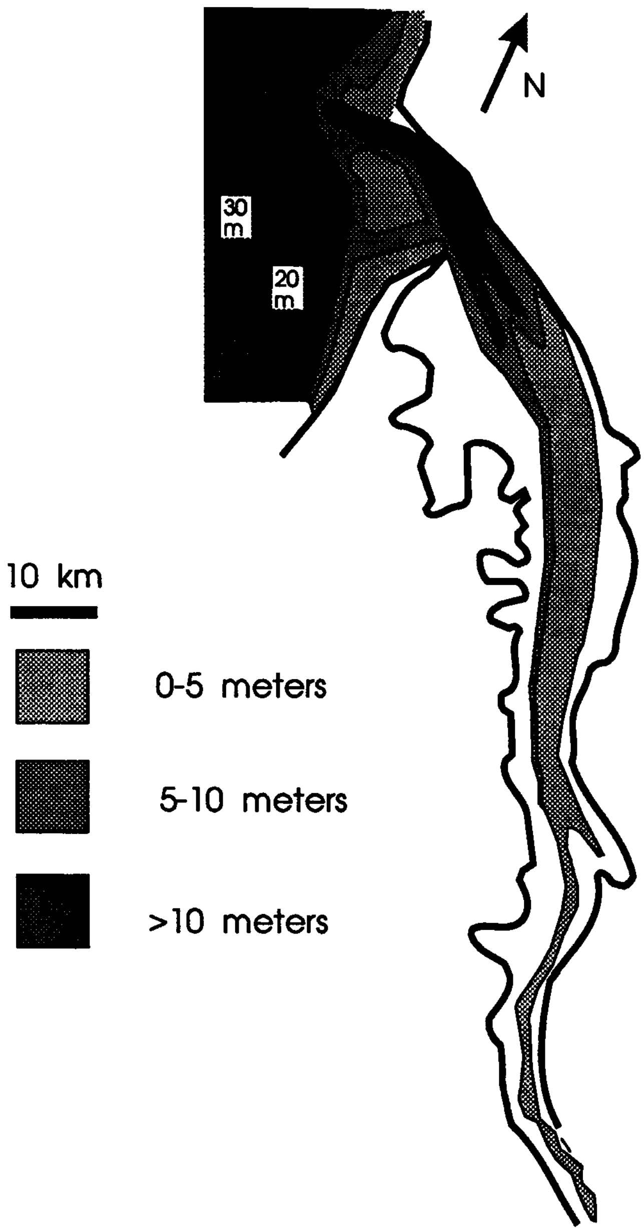

Fig. 51 Morphology of Gironde estuary, France (modified from Allen, 1991).

underlying Mississippian carbonates. Incised valleys are common components within modern estuaries (e.g. Nichols et al, 1991; Allen 1990).

Paleotopographic relief on the base of these incised valleys are suggested in isopach and net sand maps (Figs. 41 & 48) and is not uncommon in Pennsylvanian channels (e.g. Brown et al., 1990).

The twenty-foot contour also outlines several ovoid areas where sequence l strata is thin. These are surrounded by thicks of sequence l sediment within the broad western portion of the funnel. The discontinuous thins represent erosional highs on the Mississippian unconformity surface; they are interpreted to represent islands that remained above base level during much of sequence *l* deposition (Fig. 48). In the James estuary, Virginia, estuary shoals are localized over older erosional highs (Nichols et al., 1991). Islands and shoals are common features in most modern estuaries. In the Haringvliet estuary of the Netherlands, shoals separated by bifurcating tidal channels are common and are similar in scale and configuration to those in the Stewart Pool (Fig. 52).

The funnel-shaped low is bordered on the north and south by positive areas lacking *l* strata but where k strata are present. Regional isopachs and cross sections

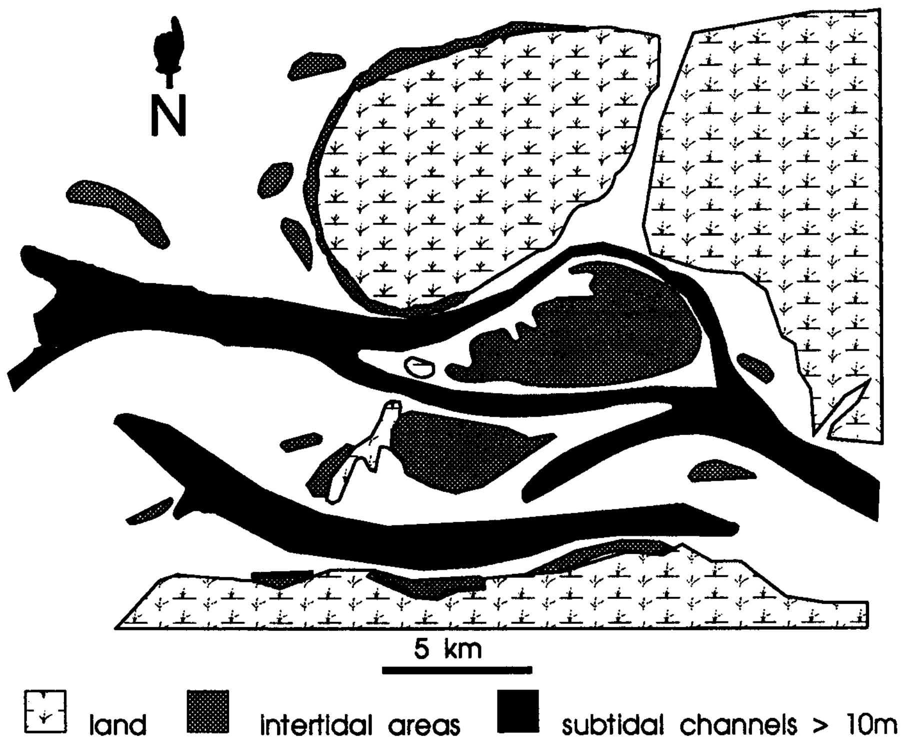

Fig. 52 Harvinglet Estuary, Netherlands (modified from Oomkens and Terwindt, 1960).

indicate that depositional strike for lower Middle Pennsylvanian strata is west-northwest to east-southeast; consequently, the thick wedge of *1* strata sits within an embayment that trends normal to paleoshoreline.

The funnel-shaped thick of *1* strata trending normal to depositional strike and surrounded on three sides by positive features, the presence of localized incised valleys within the funnel, and the presence of several islands within the broad western portion of the funnel are all indicative of estuarine geomorphology. The facies transitions from shelf carbonates into contemporaneous siliciclastics southwest of the Stewart Pool and presence of a carbonate tongue that grades laterally into Stewart Pool sandstones indicate that the incised valley at the Stewart Pool was open to marine waters to the southwest.

Description and Interpretation of Lithofacies in Stewart Pool Cores.

Oil production in the Stewart Pool is from sequence *1* sandstones of the "Gray group" (Figs. 42,43,49, & 53). Sequence *1* siliciclastics consists of 8 lithofacies that are given alphabetical designations from A through G (Table 1). Distinguishing characteristics and

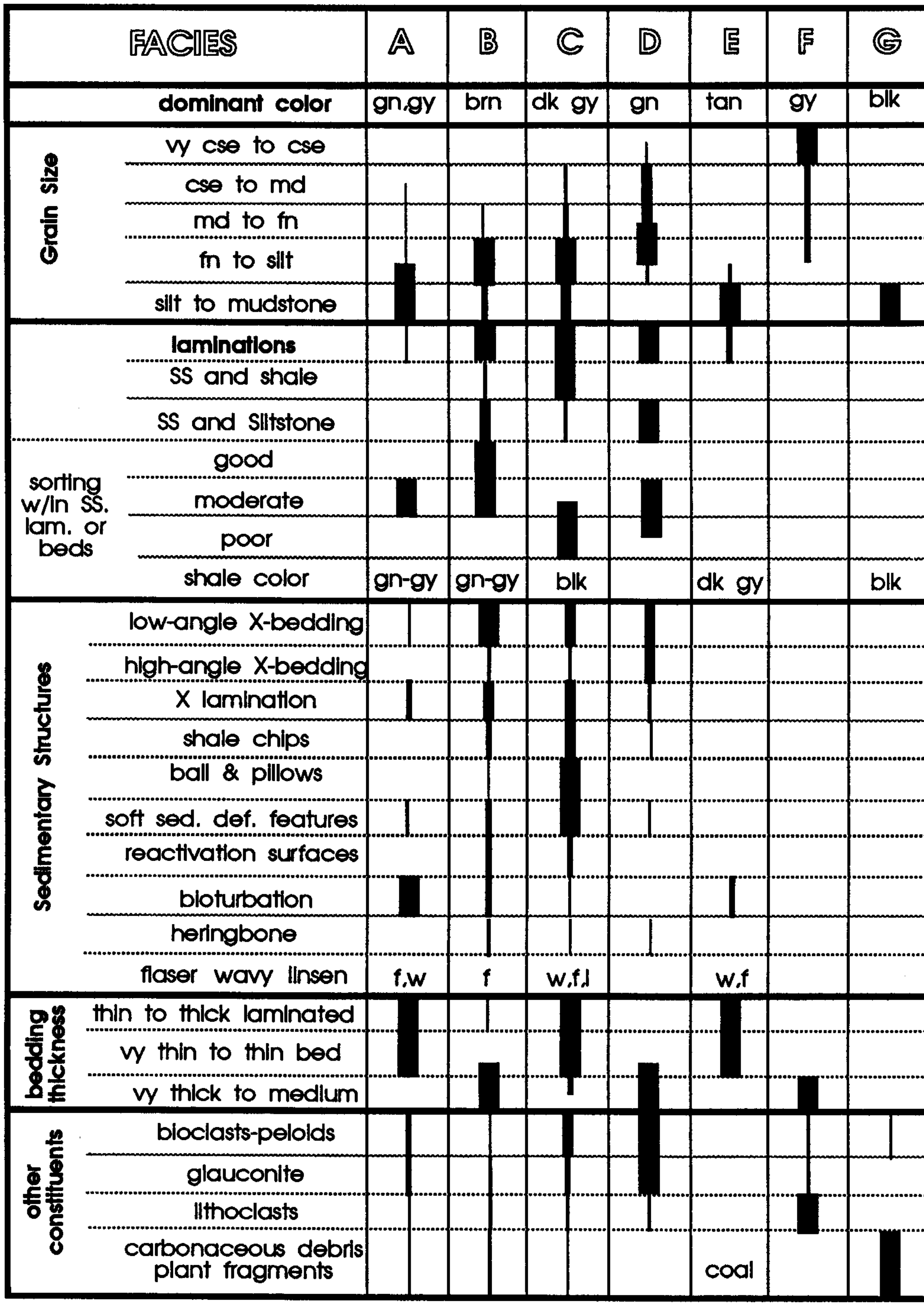

Table 1. Common sedimentary structures and constiutents in Stewart Pool cores.

Facies	distinquishing characteristics	Constituents	Interpretation
A green to light gray, bioturbated SS to Sltstn	bioturbation, abundance of shale	glauconite, rare shale clasts	shallow subtidal
B dark brown to tan, rippled and low angle X-bedded well sorted sandstone	abundant low to moderate angle cross-bedding, well-sorted sandstone, lack of shale laminations.	organic detritus, some glauconite, mud chips and carbonate mudstone clasts	intertidal channel bar to intertidal sand-flats
C gray to dark gray, rippled and low-angle X-bedded SS with dark gray to blk shale laminations	abundant soft sed. def. features, dark gray shale interbeds, and laminations, shale clasts, poor sorting, lack of bioturbation.	glauconite and peloids are locally common, mica, pyrite and plant fragments are less common.	subtidal to lower intertidal channel bar deposits.
D green to gray med. to fgr, high to low-angle X-bedded SS. w/ abnt. carbonate allochems	abundance of carbonate allochems, lack of mud, lack of bioturbation, moderate to high-angle cross-bedding	glauconite is locally abnt. and always common. Peloids, red algae, and bioclastic debris locally common.	marine dominated estuary-mouth bars
E light gray shaley siltstone with interbedded coal seams	thin coaly seams, locally bioturbated, slumped and rippled, some flaser bedding	coal seams, plant fragments and pyrite are locally common.	upper intertidal to supratidal marsh deposits
F gray conglomerate	subrounded to subangular bored, limestone cobbles to fine-grain very poorly sorted sandstone with bioclasts.	St.louis, Ste. Gen. clasts, bioclasts, glauconite.	reworked terrace deposits or wave and tidal-current cut bank deposits.
G Black Shale	Fissle shale with abundant delicate plant fragments. Disarticulated crinoid fragments at base of shale in Scott #4-4.	plant fragments in Scott #4-8; some crinoid frag.s at base of Scott #4-4.	Subtidal flooding unit
H gray to greenish gray fossiliferous shale	stenohaline fossils, starved fine-grain sandstone ripples, evidence of subaerial exposure	bryozoans, brachs., echinoderms, caliche nodules, peds.	marine shale affected by subaerial exposure

Table 2. Interpretation of lithofacies in Stewart Pool cores.

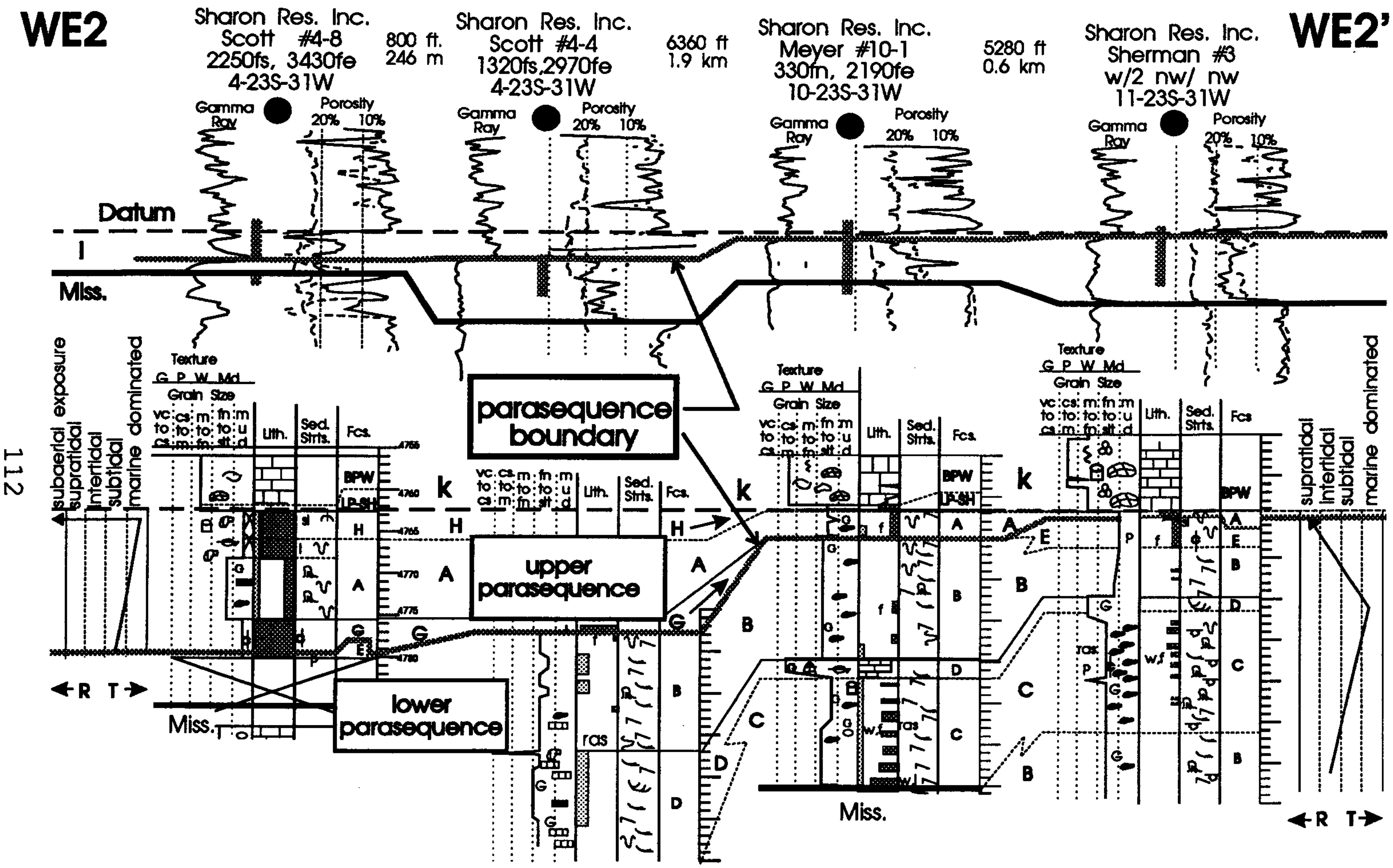

Fig. 53 Cross section WE2-WE2' showing onlap of upper parasequence and relative sea-level curves for both parasequences. See Fig. 48 for location, Fig. 49 for core and wireline log keys.

interpretation of the depositional environments of these lithofacies given in Table 2. The type log and key for Stewart Pool strata is found in Figure 49.

Bioturbated, argillaceous, fine-grained sandstone and siltstone (Facies A)

Description.- Facies A is a green to gray bioturbated fine-grained sandstone and siltstone (Fig. 54). Locally, the unit is argillaceous, flaser bedded and ripple cross-stratified. Glauconite, shale clasts, and soft sediment deformation features are locally present throughout the facies. The sandy portions of the unit are moderately to poorly sorted.

Facies A reaches a maximum thickness of 2.3 m in the western portion of the Stewart Pool in the Scott #4-8 core. In this core facies A lies above a black shale (facies G) and is gradationally overlain by a dark-green fossiliferous shale (facies H). From the Scott #4-8 core facies A thins eastward, landward, to about 30 cm in the Sherman #3 core (Fig. 53).

In both the Meyer #10-1 and Sherman #3 cores, facies A lies below sequence *k* carbonates and above all other sequence *l* siliciclastics (Figs. 43 & 49). In the Meyer #10-1, the basal three centimeters of this facies consists of a coarse to medium grained, poorly-sorted,

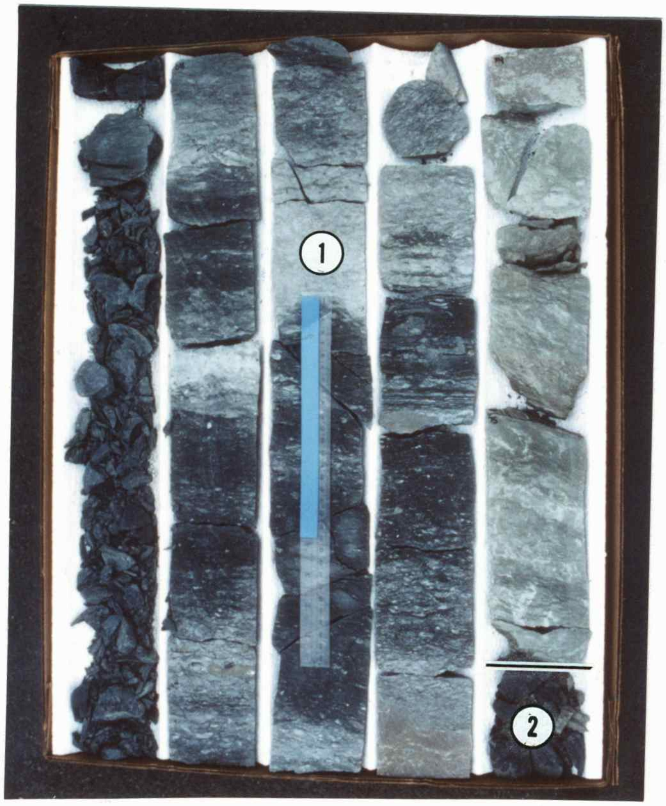

Fig. 54 Facies A (1) lies sharply above facies G (2) in the Scott #4-8 core. Scale bar = 20 cm.

Fig. 55 Facies B in Scott #4-4. 1) carbonate cemented nodule. Scale bar = 20 cm.

cross-laminated sandstone with lithoclasts and lies sharply over low-angle cross-bedded, well-sorted, fine-grain sandstones (facies B). In the Sherman #3, facies A lies gradationally above light-gray shaly siltstones with coal seams (facies E).

Interpretation.- The presence of abundant bioturbation, glauconite, and unoxidized shale layers, and the lack of diagnostic subaerial exposure features or in situ coals, suggest this unit was deposited in a subtidal marine environment. The presence of layers of ripple cross-laminated sandstone and soft sediment deformation features suggest relatively rapid deposition; however, the presence of shale, deposited from suspension, and prevalent bioturbation indicate periods of stabilization between pulses of sandstone deposition.

The localized, thin, poorly-sorted coarse to medium grained sandstone, at the base of the Meyer #10-1, indicates rapid high-energy traction deposition and may have resulted from a single high-energy event, i.e. storm or flood deposition. However, this layer may also have been deposited on a ravinement surface during a transgression event.

Facies A is interpreted to have been deposited in a subtidal marginal-marine environment close to a source of siliciclastic influx.

Well-sorted, fine-grained low-angle cross-bedded sandstone (Facies B)

Description.- Facies B is a tan to dark brown, rippled and low-angle cross-bedded well-sorted fine-grained sandstone (Fig. 55). It consists of coarse-fine couplets of fine-grained sandstone laminae to very thin beds (up to 2 cm thick) capped by layers of siltstone, green shale, or organic detritus 0.25 mm thick. Locally, this facies contains light-gray or green shale chips (up to 2 cm long), carbonate mudstone clasts, reactivation surfaces, glauconite, carbonaceous debris, soft sediment deformation features, carbonate-cemented nodules, and, rarely, forked flasers. Herringbone cross-stratification is difficult to prove in cores but may be present in several locations as well. Burrowing and flaser bedding are locally present near the top of facies B (Fig. 56).

Facies B is the dominant oil-producing facies in the Stewart Pool and ranges from 60 cm to 4.6 m in thickness. It gradationally interbeds with gray to dark-gray rippled and low-angle cross-bedded poorly-sorted sandstones with dark-gray shale laminations (facies C) and always lies abruptly above green to gray, glauconitic, low- to high-angle cross-bedded bioclast-rich sandstone (facies D).

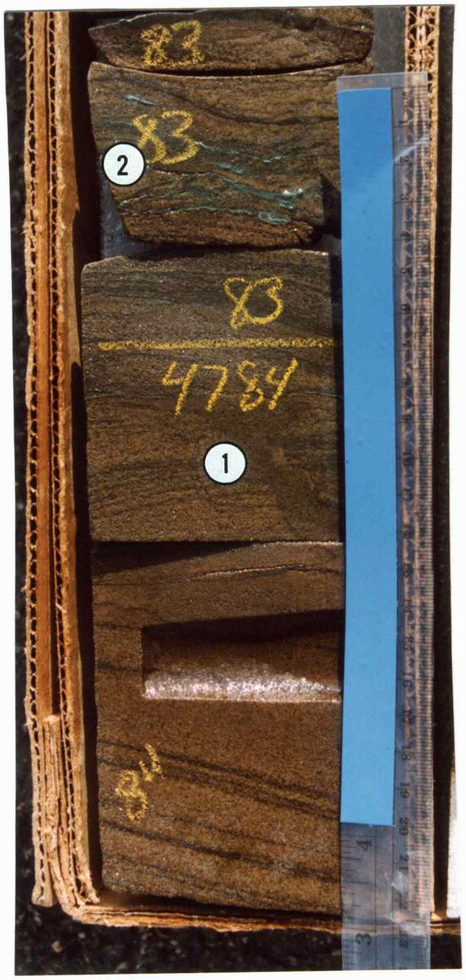

Fig. 56 Top of facies B in Scott #4-4. 1) burrow, 2) localized flaser bedding. Scale bar = 20 cm.

Fig. 57 Facies C in Sherman #3. Scale bar = 20 cm.

The unit is sharply overlain by black shale in the Scott #4-4 and by facies A in the Meyer #10-1. In the Sherman #3 and the Scott #4-8 cores, facies B is gradationally overlain by light-gray shaly siltstones with coal seams (facies E).

Interpretation.- The localized presence of glauconite, carbonate mudstone clasts, vertical burrowing and calcite-cemented nodules within the sandstone are suggestive of proximity to a marine environment. The laminations of carbonaceous debris that cap thin beds or laminations of sandstone suggest proximity to a terrestrial environment as well. The well-sorted nature of the sandstone and lack of bioclasts or other lithic fragments, compared to other facies, suggests significant working of the sands prior to final deposition.

Coarse-fine couplets in facies B indicate that periods of traction deposition were followed by intervals of suspension deposition. Flaser bedding, wavy bedding, and pinstripe lamination are all common features in tidal environments (Klein, 1971, DeRaaf and Boersma, 1971; Brownridge & Moslow, 1992; Middleton, 1992). No regular pattern of thickening and thinning of these couplets, suggestive of neap-spring cyclicity, were present in the cores. However, neap-spring cyclicity is not present in many modern tidal deposits (Amos et al., 1992; Middleton, 1992).

The forked flasers and possible localized presence of herringbone cross-stratification are also suggestive of tidally influenced deposition. Herringbone cross-stratification is difficult to discern in core; however, indications of it are locally present. This can be produced by waning unidirectional currents but may be common in and are considered suggestive of reversing tidal currents (DeRaaf and Boersma, 1971). Herringbone cross-stratification requires similar ebb and flow tidal current velocities; a rare occurrence in most tidal deposits (Nio and Yang, 1991).

The lack of bioturbation in this facies may result from high sedimentation rates, the presence of brackish or schizohaline water masses, or some combination of both. Both high sedimentation rates and brackish or schizohaline water masses are common in estuaries (Klein, 1971; Rahmani, 1988; Clifton, 1982; Smith, 1988)

In the lower part of the facies, the presence of soft sedimentary deformation features and lack of burrowing indicate rapid deposition. However, the burrowing near the top of the facies and the gradational transition upward into finer-grained facies E indicate that depositional rates and energy level decreased up section and suggests shoaling. The gradational vertical transition from facies B into coaly facies E also indicates that this facies locally aggraded up into a supratidal environment. Middleton (1992) states that flaser and wavy bedding are particularity suggestive of tidal deposition when they fine upward in response to prograding tidal flats.

Facies B is similar to the lower portion of facies B of Rahmani (1988). Rahmani ascribed sandstone laminations (pinstriped bedding) to tidal processes and low-angle cross-bedding to wave deposition in the upper shoreface. Moderate to high-angle cross-bedding and ripple cross-stratification, also locally present in facies B, are typical of sandy intertidal flats adjacent to tidal channels in the Bay of Fundy (Dalrymple, 1978) and in the Willapa Bay in Washington (Clifton, 1982). The decrease in grain size and increase in bioturbation upsection through facies B are characteristics ascribed to aggrading intertidal sand-flats in the North Sea (Weimer, Howard and Lindsay, 1982).

Facies B is similar to the "horizontally bedded" facies of Oomkens and Terwindt (1960) in the Haringvliet Estuary, Netherlands. They described this facies as:

> "medium- to fine-grain, well-sorted sand alternating with very thin clay beds...small-scale crosslamination and parallel

lamination... Burrows occur in places where deposition is slow. Some glauconite, shell debris and peat detritus are found."

The horizontally bedded facies was found on "relatively flat parts of channel slopes and on submerged shoal surfaces..."

Facies B is interpreted to have been deposited by waves and tidal currents in intertidal-bars or lower-intertidal sand-flats adjacent to tidal channels.

Poorly sorted Sandstone with black shale laminations (Facies C)

Description.- Facies C (Figs. 57 & 58) is gray to dark-gray, rippled and low-angle cross-bedded, poorly-sorted sandstone (up to 50 cm thick) with dark gray to black shale laminations (up to 1 cm thick). Grain size in individual sandstone laminae or thin beds ranges from coarse to very-fine; although fine sandstone is predominant. The sandstones are interlaminated or thinly interbedded with dark-gray to black, slightly micaceous, pyritic shale. The shale rarely contains plant fragments, horizontal burrows, and green mottling.

Wavy-bedded intervals are common throughout facies C. They range from several millimeters to 15 cm in thickness and may contain numerous sandstone-shale

Fig. 58 Facies C in
Meyer #10-1.
Scale bar = 20 cm.

Fig. 59 Facies D (1) sharply overlain by facies B (2) in Sherman #3 core. 3) possible diurnal tidal drapes.
Scale bar = 20 cm.

couplets. Wavy-bedded intervals are separated by low-angle to moderate-angle cross-bedded, distorted, or, more rarely, structureless sandstone beds that are 4 to 50 cm thick and locally display erosive bases. Locally, the sandstones contain coarse-fine couplets similar to those found in facies B. Soft sediment deformation features, shale clasts, and balls and pillows are abundant throughout the facies. Reactivation surfaces, high-angle cross-bedding and linsen bedding are present but rare. Locally, fine bioclastic debris, glauconite, and chert fragments are common constituents. The heavily abraded bioclastic constituents in the sandstones include brachiopods, echinoderms, bryozoans and red algae. Carbonaceous debris, plant spores, and plant fragments are locally present as well.

Intervals of facies C range from 60 cm to 4.3 m in thickness. It is gradationally interbedded with facies B or is gradationally overlain by green to gray bioclast-rich, cross-bedded, medium- to fine-grained sandstone (facies D).

Interpretation.- Facies C is similar to facies B in that the variety of constituents indicate deposition close to marine and coastal environments. The two units interbed gradationally suggesting they are lateral equivalents to one another. However, facies C differs from facies B in two important ways: 1) facies C contains considerably more shale interbeds, and 2) sandstones in facies C are poorly sorted and contain considerably more coarse bioclastic and lithic fragments.

The poorly-sorted nature of the sandstones and wide variety of constituents suggest less active reworking of the sandstones by currents prior to final deposition than occurred in facies B. The ubiquitous thin beds or laminations of black shale in this facies indicate considerable deposition by suspension between pulses of sandstone deposition. The abundance of soft sediment deformation features and lack of burrows indicate rapid deposition. The presence of mud rip-up clasts and the localized erosive bases on some of the sandstones indicates deposition near currents with erosive power and suggests proximity to active channels. This unit also lacks evidence of shoreface deposition such as hummocky cross-stratification or extensive burrowing.

The abundant evidence for suspension deposition, and the lack of oxidation of the organic-rich shales and subaerial exposure features suggests subtidal deposition. Sandstones in this facies were probably laid down during strong pulses of tidal-, wave- or river-induced current in a subtidal setting.

Facies C is very similar to the "cross-bedded" facies described by Oomkens and Terwindt (1960) in the Holocene Haringvliet Estuary in the Netherlands. They report the facies as:

> "...poorly sorted sand with very thin clay beds and laminae...clay pebbles are abundant...pieces of wood, echinoid fragments and some glauconite...no burrows were found".

This facies was reported to be found in the lower portion of subtidal channel bars.

Facies C is also similar to Wood and Hopkins (1989) SS/SH facies in the Glauconitic Sandstone of Alberta. They interpreted this type of facies to have been deposited in "low-energy muddy portions of bars formed in... channels of an estuary." Facies C is also equivalent to facies D and E of Rahmani (1988) which he interpreted to represent subtidal lower-estuary channel deposition.

Facies C is interpreted to represent subtidal deposition in or near estuary channels.

Green to Gray bioclast-rich cross-bedded sandstone to grainstone (Facies D).

Description.- This facies is green to gray, fine- to medium-grained cross-bedded sandstone with abundant glauconite and bioclastic debris (Fig. 59). In the Meyer

Fig. 60 Sandy bioclastic packstone (facies D) in Meyer #10-1.
Scale bar = 20 cm.

Fig. 61 Carbonate lithoclasts at top of facies D in Scott #4-4 core. Scale bar = 20 cm.

Grain size and absence of mud separates this unit from the more landward oriented tidal channel or lower-intertidal-flat sands.

Gray argillaceous siltstones and shales with coal seams (Facies E)

Description.- Facies E occurs in only two cores, the Sherman #3 and Scott #4-8. In the Sherman #3, facies E is a light-gray, flaser to wavy bedded, shaly siltstone and very-fine-grain sandstone with interlaminated coal seams and dark gray shales (both less than 1 cm thick; Fig. 62). Bioturbation, soft sediment deformation features, and cross-lamination are locally apparent. The unit is distinguished from facies A by its lighter color, the lesser degree of bioturbation and presence of thin coal seams.

In the Scott #4-8, facies E consists of a pyritized coal, 15 cm thick, with vitrinite seams several millimeters thick (Fig. 63). In both cores where it occurs, facies E lies gradationally above facies B. In the Sherman #3 it is about 75 cm thick and grades upward into facies A. In the Scott #4-8 facies E is about 15 cm thick and is sharply overlain by black shale (facies G).

Interpretation.- The flaser beds and ripples indicate facies E is, in part, the result of alternating

Fig. 62 Facies E (1) and facies B (2) in Sherman #3 core. Scale bar = 20 cm.

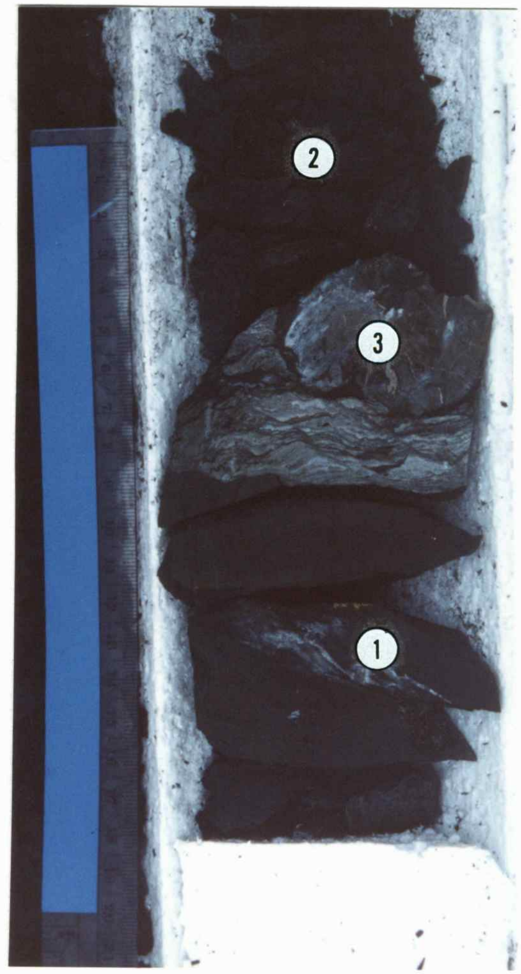

Fig. 63 Facies E (1) and facies G (2) in Scott #4-8 core. 3) Partially pyritized log. Scale bar = 20 cm.

traction and suspension deposition. Localized bioturbated intervals suggests the unit accumulated more slowly than facies B,C, or D. The presence of coal indicate supratidal coastal deposition.

Facies E is similar to facies F and H of Rhamani (1989). It is also similar to mixed tidal-flat facies in the Jade Bay, Germany (Weimer, Howard and Lindsay, 1982). In both cases these units are interpreted to represent upper-intertidal deposition and commonly overlie facies B type lithologies.

Facies E is interpreted to represent upper-intertidal to supratidal marsh deposition.

Gray Limestone Conglomerate (Facies F)

Description.- Facies F is a cobble to pebble conglomerate of subrounded to subangular limestone clasts (Fig. 64). Clasts consist predominately of Mississippian limestones, although some are of indeterminate origin. Commonly, clasts are bored on all surfaces. The matrix consists of poorly sorted coarse- to very-fine-grained sandstone. The conglomerate is split by a bed of medium- to fine-grained glauconitic sandstone (Facies D) that is 30 cm thick (Fig. 43). This bed contains lithoclasts and abundant bioclastic debris including crinoids.

Facies F is present only at the base of sequence *1*,

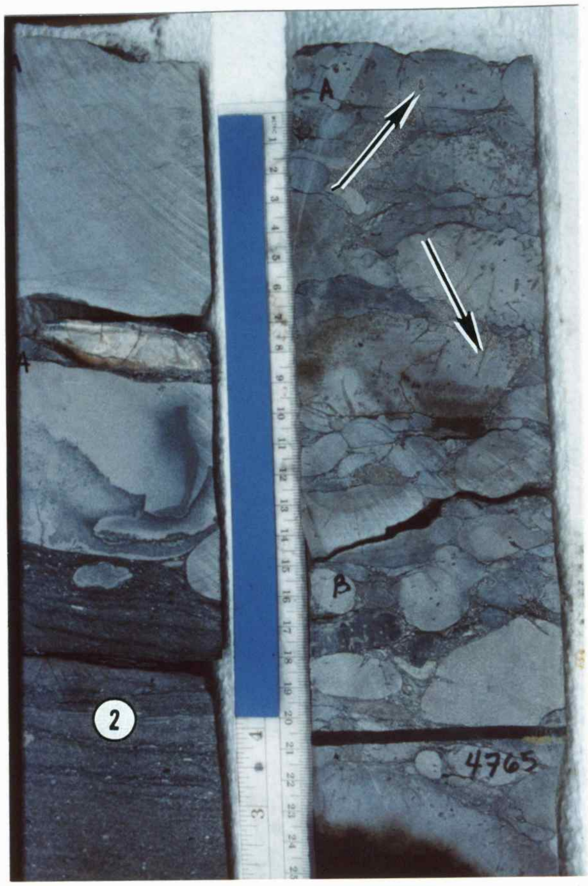

Fig. 64 Gray limestone conglomerate (facies F) interbedded with biocalstic sandstone (facies D; 1) in the Sherman #5 core. Scale bar = 20 cm.

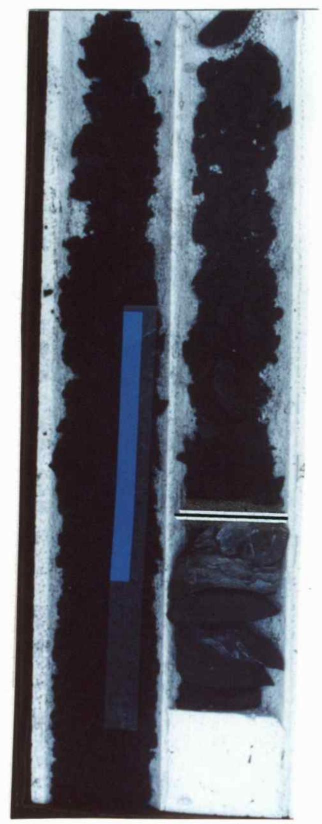

Fig. 65 Black shale (facies H) overlying facies E in Scott #4-8 core. Scale bar = 20 cm.

in the Sherman #5, where it is about 1.5 m thick. It abruptly overlies Ste. Genevieve oolitic grainstone and is sharply overlain by facies B.

Interpretation.- Subrounded clasts suggest significant reworking prior to final deposition. Pervasive boring on all sides of the clasts and interbedded bioclast-rich sandstone suggest this unit was extensively reworked in the marine environment. The presence of some clasts of indeterminate origin may indicate that they were introduced to the area from distant sources, and suggests that facies F may have originally been a terrace deposit.

The position of facies F within the incised valley is important in the interpretation of this facies. Cross section NS2 (Fig. 43) reveals the relative paleotopographic position of the Sherman #5 during deposition of sequence *1*. In the Sherman #5, sequence *1* strata are about 9.2 m thinner than sequence *1* strata in the Sherman #3. This indicates that the Sherman #5 was located on a shallower portion of the incised valley than was the Sherman #3. Cross-section NS2 also reveals that the conglomerate in the Sherman #5 is laterally equivalent to facies D in the Sherman #3. This suggests that the conglomerate may have been deposited roughly contemporaneously with facies D in the Sherman #3.

Presumably wave energy was highest during deposition of facies D and may have been strong enough to erode estuary banks or rework older terrace conglomerates in the Sherman #5.

Black Shale (Facies G)

Description.- Facies G is fissile black shale (Fig. 65) that is present only in western portion of the Stewart estuary in the Scott #4-8 and Scott #4-4 cores. In the Scott #4-8, delicate fern fronds and plant fragments are the only fossils; however, in the Scott #4-4 core the base of the unit contains a few disarticulated echinoderm fragments.

The Scott #4-4 core contains only the basal 5 cm of this facies in the top of the core. In this well the black shale sharply overlies facies B. Facies G is about 1.4 m thick in the Scott #4-8 and lies sharply above facies E.

Interpretation.- The fine-grained terrigenous clay and unoxidized organic material, including abundant plant fragments up to several centimeters long, suggest that this unit was deposited by suspension in a low-energy subtidal setting. The thinly laminated nature of the shale and excellent preservation of delicate fern fronds also indicate that the sediment was not heavily bioturbated. The lack of bioturbation suggests facies G was deposited either very rapidly or in an anoxic environment. Deposits similar to facies G have been reported as basal brackish salt marsh deposits associated with Holocene transgression along the Virginia coast (Finkelstein and Ferland, 1987). These deposits overlie peat deposits that lie directly upon older pre-Holocene sediment. Plant-rich black shales commonly overlie coal in Illinois basin cyclothems. In the Illinois basin, localized black shales of this type are interpreted to represent rapid deposition in shallow, anoxic, coastal settings with poor water circulation (Zangrel and Richardson, 1963).

Green to Gray Fossiliferous Shale (Facies H)

Description.- Facies H is a green to gray fossiliferous shale with localized laminations of fine-grained glauconitic sandstone (Fig. 66). Unabraded bryozoans, brachiopods, and echinoderms are the most common fossils. The unit contains peds with slickensides and localized caliche nodules (Fig. 67).

Facies H is only present in the Scott #4-8 core where it is about a meter thick. This facies lies gradationally above facies A and immediately below sequence *k* strata.

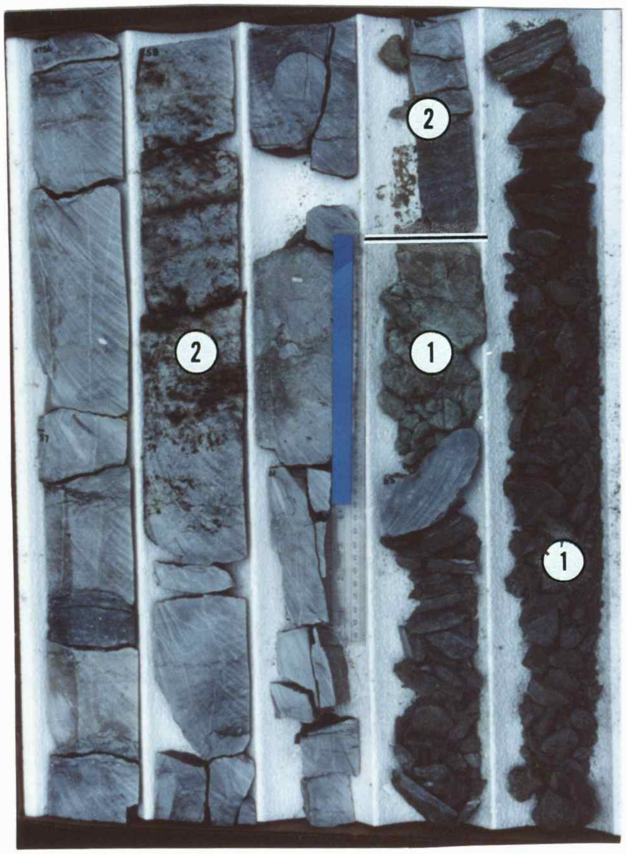

Fig. 66 Facies H (1) overlain by sequence k carbonates (2) in the Scott #4-8 core. Scale bar = 20 cm.

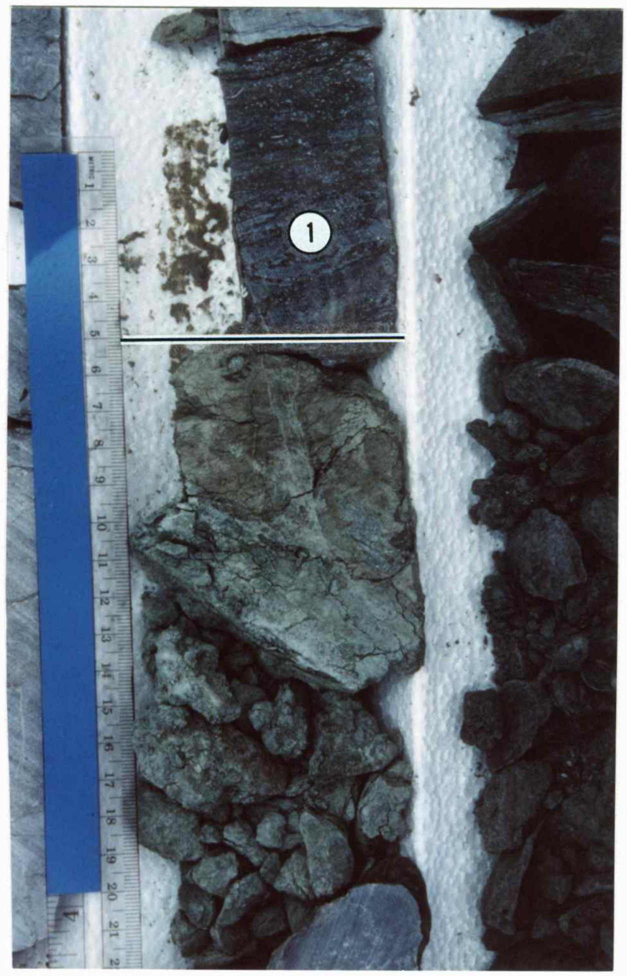

Fig. 67 Top of sequence l (facies H) in the Scott #4-8 showing well-developed soil profile. 1) facies LP-SH of overlying sequence k. Scale bar = 20 cm.

Interpretation.- Facies H is interpreted to have been deposited in a low-energy, subtidal, marine environment that was later effected by subaerial exposure.

Comparison of Stewart Estuary to Modern Estuarine Models.

The sedimentology of many modern estuaries has been described in terms of a tripartite depositional model (Nichols and Biggs, 1985; Allen, 1990; Rahmani, 1988, Nichols et al., 1991). This model divides estuarine sediments into a marine-dominated sand-rich lower-estuary facies, a low-energy mud-rich middle-estuary facies, and a sand-rich river-dominated upper-estuary facies.

Lower-estuary facies are characterized by wave and tidal bedforms and marine fossils. Within the mud-rich middle-estuary, a turbidity maximum is created by a plume of fresh water that extents out over dense saline water. Clay accumulated from suspension in the middle estuary due to a combination of four factors: 1) decreased shear of fluvial flow as the river opens into the estuary, 2) decreased shear of fluvial flow as less dense seaward flowing fresh water passes over more dense landward flowing marine water, 3) flocculation of clays due to a rapid decrease in salinity, and 4) tidal asymmetry.

Flood-directed tidal flows are greater than ebb-directed tidal flows in middle and upper estuaries (Allen, 1991; Nichols et al., 1991).

Tidal asymmetry not only helps create the turbidity maximum but also tends to pond river-derived sands in upper estuaries. River-derived sand also tends to be deposited in upper estuaries in response to a decrease in fluvial current flow at sea-level and due to dissipation of the current entering the estuary funnel.

Cores examined in the Stewart estuary show only marine- and tide-dominated sandstone facies. No significant subtidal mud-rich units were encountered in the estuary funnel that would indicate the development of a turbidity maximum. Similarly river-dominated sandstones of the upper estuary were not found. The reasons for the lack of typical mid- or upper-estuary lithologies in the Stewart estuary may be the result of a combination of two factors: 1) lack of appreciable fine-grained siliciclastics and fresh water being supplied from terrestrial sources, and 2) dominance of wave and tidal processes over river influx. Mid- and upper-estuary facies may have been attenuated beyond recognition in the estuary, or shifted upstream, landward, of the estuary funnel. Further investigations of the lithologies in the incised-valley upstream of the

Stewart Pool may aid in determine whether mid- or upper-estuary facies are present there. The few wells that have penetrated the incised valley landward of the estuary funnel report only the presence of chert conglomerates in the valley.

The shale-filled incised-valley just north of the Stewart Pool (Figs. 41 & 48) may contain mid-estuary facies. However, core data is not available in this area.

Source of Sand

The source of sand for the Stewart estuary cannot be determined without a thorough petrographic investigation. However, several observations are germane to this problem. 1) The presence of clean carbonate in the 1 zone of the #1 Linder, to the northwest of the estuary, suggests that longshore drift from that direction was not responsible for sand accumulation in the estuary. 2) The Mississippian Ste. Genevieve is extremely sandy locally (Blaine Dey, pers. comm.) and subcrops in the Stewart estuary. Shoreline or submarine erosion of the Ste. Genevieve may have provided much of the sand.

Several modern analogs indicate that shoreface and submarine erosion are important in providing estuarine sands. Outer estuary sands are provided by shoreline erosion of the Pleistocene deposits in James Bay, Virginia (Nichols et al., 1991). In the sand-rich Minas Basin portion of the Bay of Fundy, estuarine sand is supplied by erosion of Triassic sandstone cliffs surrounding the estuary (Amos and Long, 1980). Similarly, sediment in the Mont Saint Michel estuary in northern France is supplied almost completely by submarine erosion (Bourcart and Jacques, 1960).

Geologic History of the Stewart Estuary

Valley incision and structural grain

Incision of the Stewart estuary into Mississippian strata probably began during a worldwide drop in sea-level marking the end of the Kaskaskia cratonic sequence (Sloss, 1962; Fig. 68). While core is not available from the base of the deepest portions of the incised valley, it is probable that low stand flood-plain shales or fluvial conglomerates may be locally preserved there. Incised-valley-fill sequences within the Morrow of the western Hugoton embayment frequently contain basal lowstand deposits (Sonnenberg et al., 1990).

The sinuous incised valley that contains the Stewart Pool trends WNW-ESE. However, the shale-filled incised-valley and the estuary funnel trend NE-SW and are aligned normal to the depositional strike of Pennsylvanian units in the Hugoton embayment (Figs. 35 & 36; Merriam, 1963). Isopach maps indicate that estuarine islands and shoals are extensions of paleotopographic noses that extend into the estuary funnel and also display a NE-SW trend (Fig. 48). The discrepancy between the trend of the incised valley that contains the Stewart Pool (WNW-ESE) and many of the paleotopographic features in the area (NE-SW) may indicate that the incised valley was cut before the development of the NE-SW structural grain and prior to development of the estuary.

Identification of parasequences and interpretation of the depositional history of sequence 1 siliciclastics.

Broadening of the incised valleys into a funnel shape was probably accomplished by marine and tidal erosion (Pillsbury, 1956; Langbein, 1963; Middleton, 1992) during sequence *1* transgression.

Sequence *1* consists of two parasequences (Fig. 53). The boundary between the parasequences is picked at the base of a flooding unit below which a basinward shift in facies did not occur.

The lower parasequence (up to seventy feet thick) contains the producing sandstones of the Stewart Pool; the upper parasequence (up to fifteen feet thick) offlaps

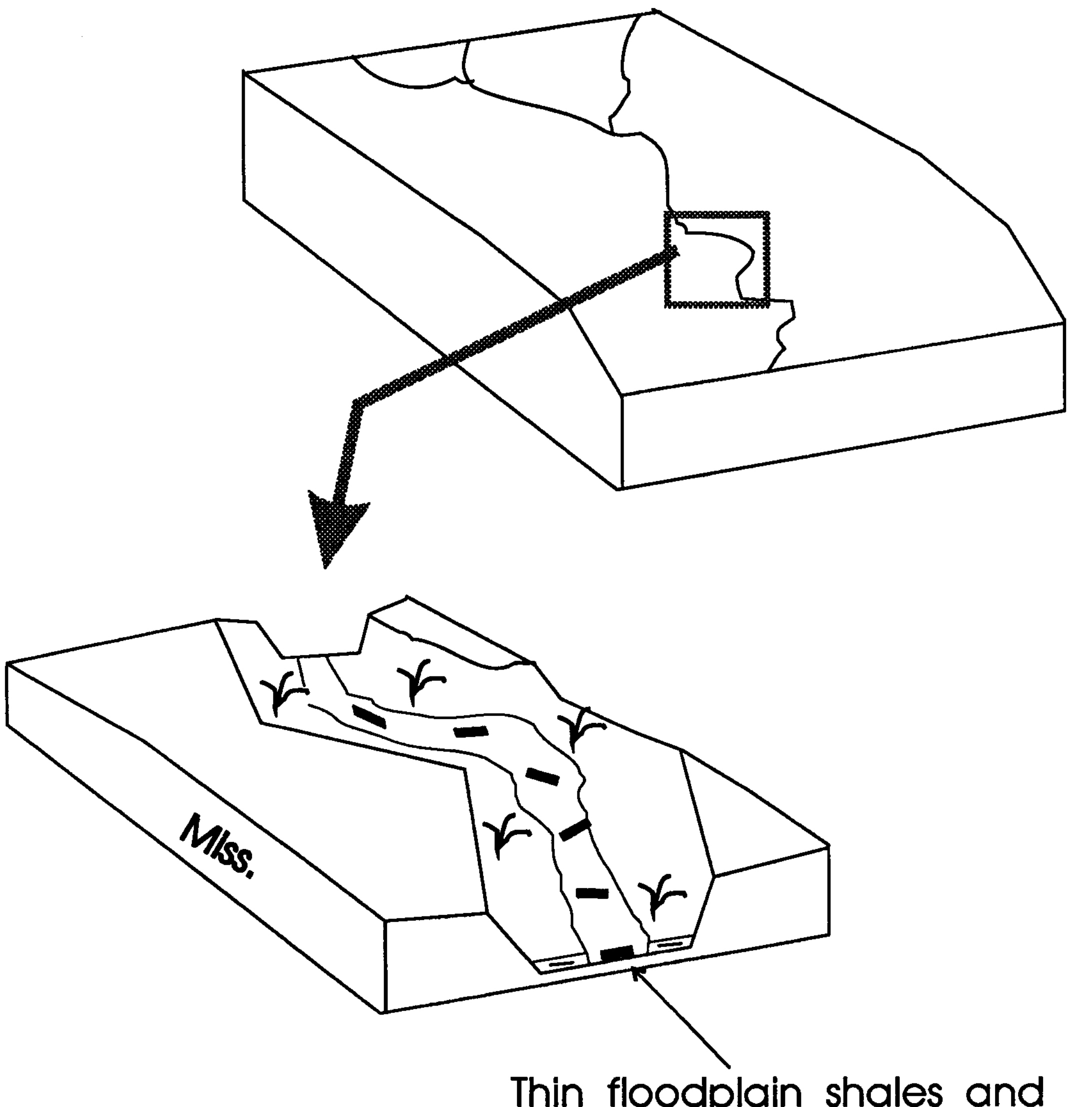

Fig. 68 Valley incision after withdrawal of Mississippian seas.

the lower parasequence and is restricted to the distal portion of the estuary, where it filled available accommodation space.

lower parasequence.- All the core studied, except the Scott #4-8 core, is from the lower parasequence. The depositional history of the lower parasequence is interpreted from the vertical succession of lithofacies in five cores and from wireline-log cross-sections. In the Stewart Pool the lower parasequence contains both transgressive and regressive phases of deposition.

transgressive phase.- The Sherman #3 core is the most landward of the cores studied; however, it also contains core from the deepest portion of the incised valley. The base of this core lies about 10 feet (3 m) above the Mississippian. The basal 3 m of core in this well consists of intertidal sand-flat deposits (facies B) that grade vertically up into subtidal, proximal-channel deposits (facies C). This facies transition may reflect either lateral migration of tidal channels or transgression. However, it is interpreted to be the result of initial transgression based upon strong evidence for continued transgression in overlying facies. As base level rose subtidal estuarine sandstones transgressed over intertidal sandstones (Fig. 69).

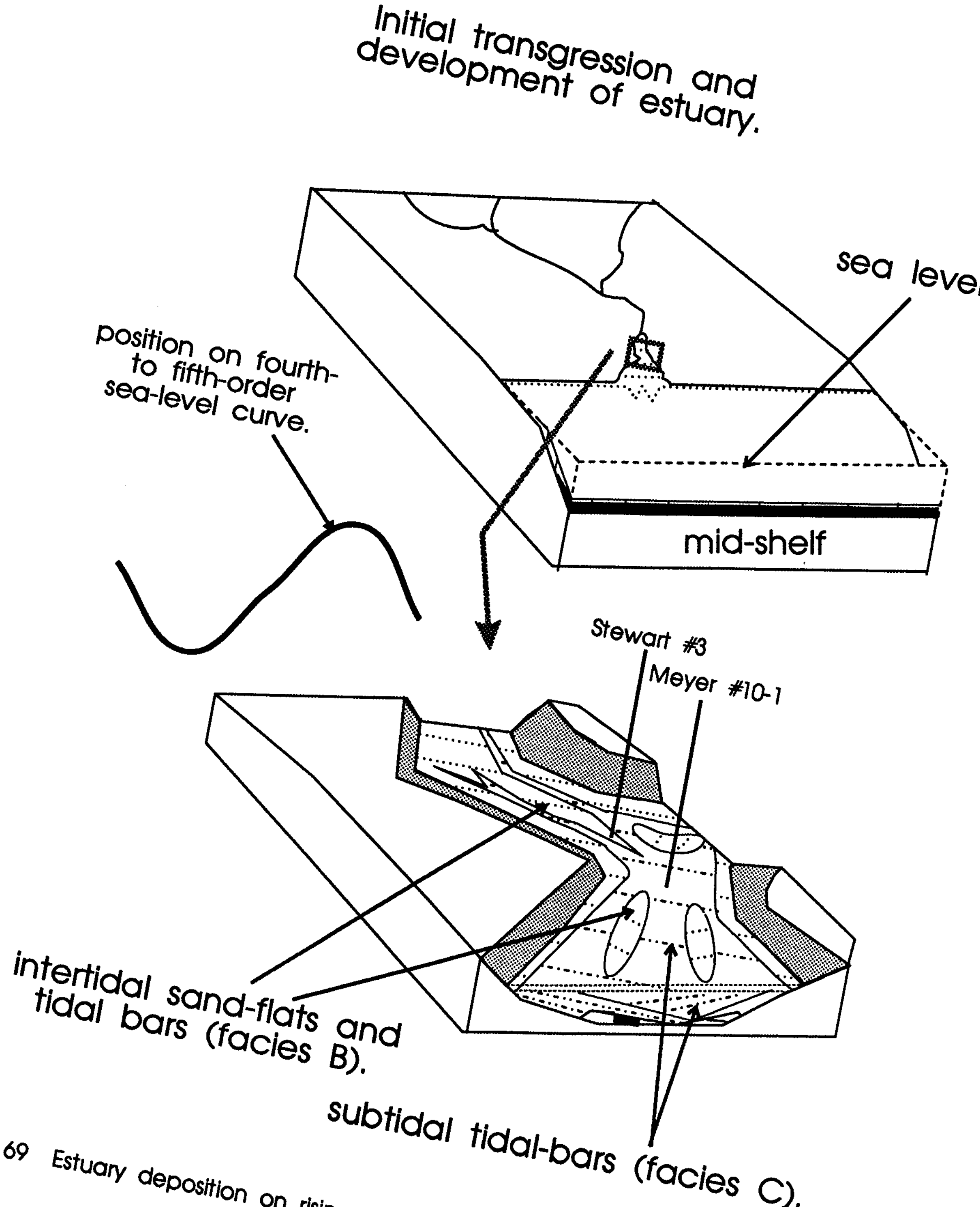

Fig. 69 Estuary deposition on rising limb of sea-level curve.

In all cores studied, subtidal proximal-channel sandstones (facies C) are gradationally overlain by lower estuary-bar sandstones and carbonates (facies D). This facies transition is interpreted to represent transgression based upon three lines of evidence. First, the ubiquitous nature of this facies transition throughout the estuary suggests that the change from subtidal proximal-channel deposition to estuary-mouth bar deposition was not a localized autocyclic phenomenon. Second, facies D does not interbed with, nor is it gradationally overlain by facies C which also suggests that the facies C-D transition did not result from autocyclic processes, but from a rise in base level. Third, facies D climbs up through the stratigraphic succession landward (Fig. 53) and indicates that estuary-mouth bars migrated landward, up the estuary over time; a condition that can occur only with rising base level.

The presence of bioclastic grainstones, packstones, and coarse, bioclast-rich sandstones indicate the point at which the highest energy facies were deposited in the core; and the point at which the succession was most heavily influenced by open-marine conditions. This suggests that base level reached a maximum elevation during deposition of the lower-estuary-bar deposits

Near maximum inundation of estuary.

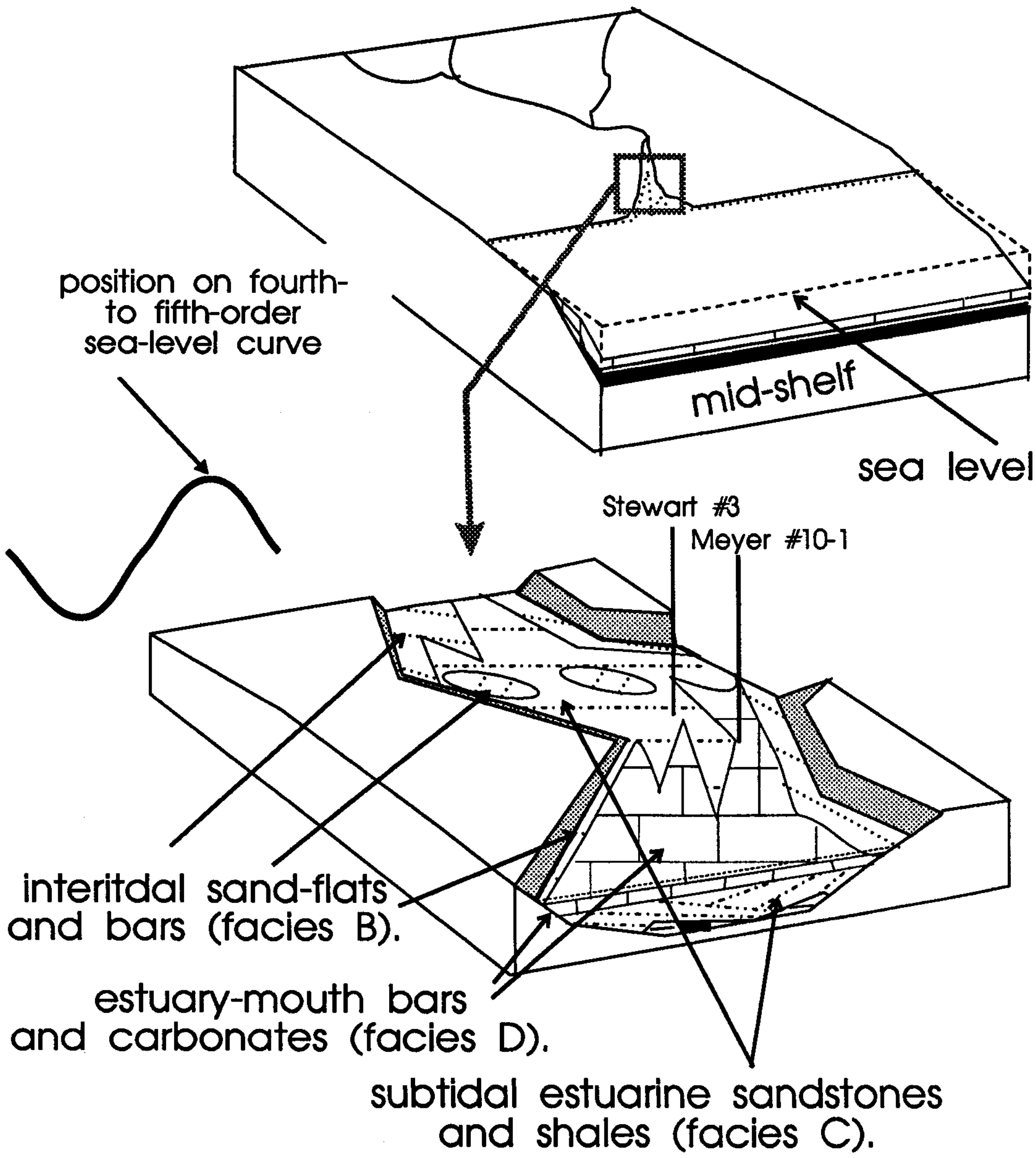

Fig. 70 Estuary deposition at maximum inundation.

(facies D; Fig. 70).

Only in the basal half of the Sherman #3 core (Fig. 53) is the deepening upward transition from intertidal facies (facies B) through lower-estuary-bar facies (facies D) complete.

regressive phase.- Intertidal sand-flat deposits (facies B) overlie the lower-estuary-bar deposits (Fig. 53). This relationship indicates progradation of intertidal sand-flats over subtidal, lower-estuary bars and shoals. Sharp boundaries between facies D and B may reflect small-scale scour at the base of lower-intertidal channel deposits. Supratidal coaly deposits (facies E) lie gradationally above intertidal sand-flat facies in the Sherman #3 core. Wireline logs indicate that the same relationship occurs in the Scott #4-8 core, although the pay sand below facies E was not available for study. The vertical relationship between these facies indicates that intertidal bars and sand-flats may locally aggrade to, or slightly above sea level and reflects continued regression. However, since marsh deposits (facies E) are not present in the Meyer #10-1, the development of these deposits may have been a local phenomenon.

The facies transition from lower-estuary-bar deposits through intertidal sand-flat deposits and, locally, up into supratidal deposits suggests a drop in

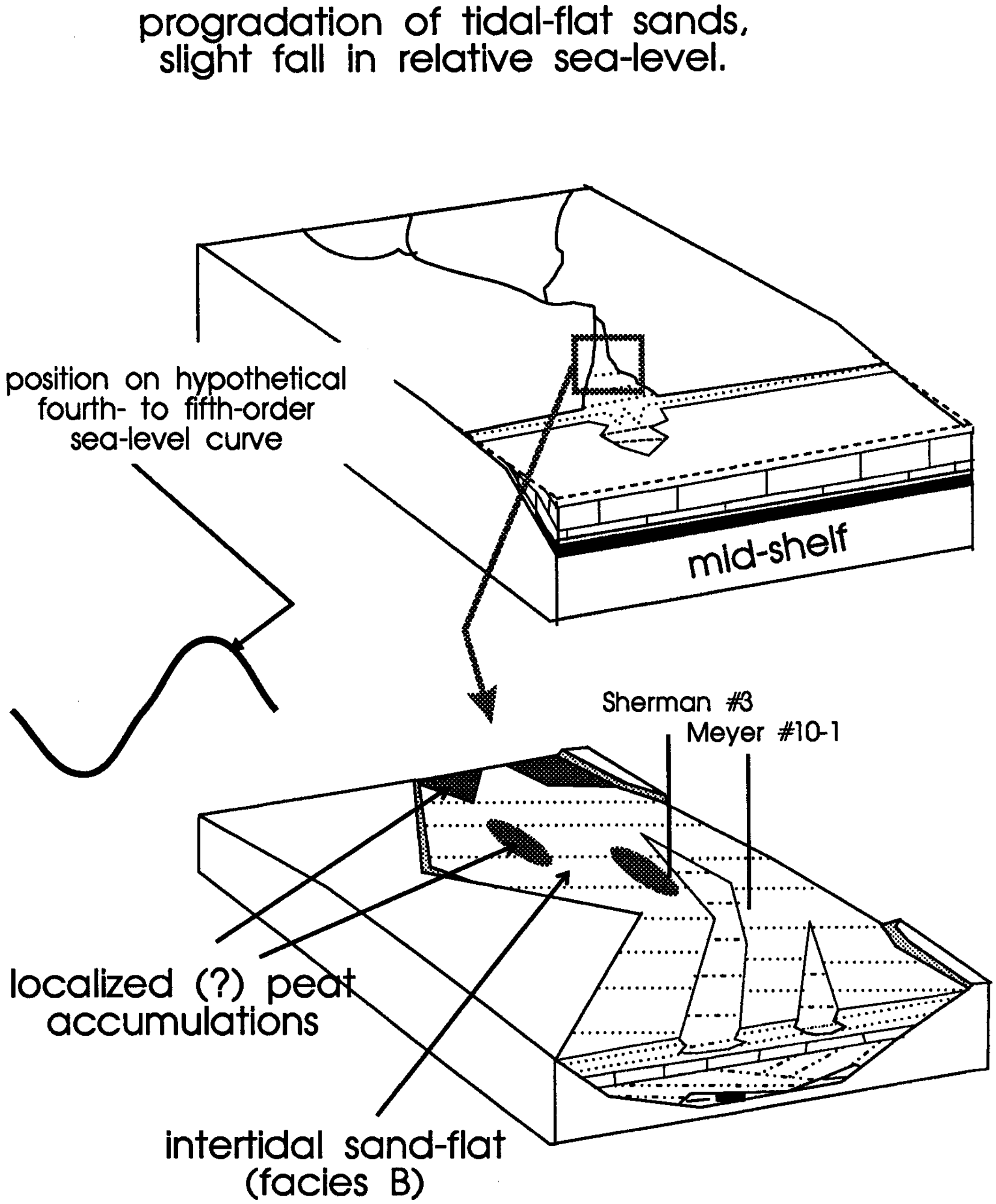

Fig. 71 Estuary deposition during falling limb of sea-level curve.

base level over the top half of the lower parasequence (Fig. 71).

upper parasequence.- Wireline-log cross-sections and cores show that the upper parasequence is restricted to the western half of the estuary and offlaps the lower parasequence (Fig. 47 & 53). The most complete succession of the upper parasequence is in the Scott #4-8 core.

In the Scott #4-8 core, the vertical transition from a coal (facies E) into a subtidal black shale indicates a rise in base level, and the black "hot" shale represents a flooding unit. Wireline logs and core data indicate that the black shale facies, present in both Scott cores, extends only immediately landward of the Scott #4-4 (Fig. 53).

In the Scott #4-8 core, the black shale grades vertically into heavily bioturbated, subtidal sandstones (facies A). This facies transition suggests that water circulation improved through time as transgression continued. Heavily bioturbated subtidal sandstones (facies A) thin landward from about 3 m in the Scott #4-8, to about 30 cm in the Sherman #3, and overstep the black shale facies (Fig. 53). In the Sherman #3 core, subtidal sandstones (facies A) of the upper parasequence appear to lie gradationally upon lower parasequence supratidal marsh deposits (facies E). The gradational appearance of this contact probably results from penetration of burrowing organisms into underlying marsh sediments.

Subtidal open-marine shales (facies H) sit gradationally above subtidal sandstones in the Scott #4-8 core. The presence of unabraded stenohaline organisms (bryozoans, echinoderms and brachiopods) indicate these shales were deposited in the most open marine conditions within sequence *1* and suggests that base level continued to rise after deposition of the subtidal sandstones. Marine shales are not present in cores landward of the Scott #4-8. This indicates that the marine shales graded laterally into and onlapped the subtidal sandstone facies (facies A) landward, or that they were removed by post-sequence-*1* erosion.

upper sequence 1 boundary.- The basinward shift in facies that delineates the top of sequence *1* is apparent at the top of the Scott #4-8 (Fig. 53) and Sherman #3 cores. In the Scott #4-8 core, subtidal open marine shales (facies H) contain peds with slickensides (Fig. 67). Caliche nodules are locally present throughout facies H and the top half of facies A and indicate significant subaerial exposure occurred prior to deposition of overlying sequence k carbonates.

In the Sherman #3 core, evidence of a basinward shift in facies at the top of sequence *l* is more cryptic; however, slickensided peds within facies A are locally apparent. Evidence for subaerial exposure of sequence l siliciclastics in the Meyer #10-1 is not apparent. It is possible that much of the evidence for subaerial exposure in the Meyer #10-1 and Sherman #3 cores were removed by erosion or ravinement prior to accumulation of sequence *k*.

Sea-level history: its Effects on Estuarine Sedimentation and Comparison to its Effects on Correlative Carbonates.

Parasequences in correlative carbonates

Wireline-log signatures in wells penetrating equivalent sequence *l* limestones seaward of the estuary do not reveal the presence of parasequences. This suggests that the sea-level fluctuation associated with the development of the upper parasequence was not of sufficient magnitude to significantly change the nature of carbonate accumulation on the shelf. The maximum thickness of onlapping strata in the upper parasequence between the Scott #4-8 and Sherman #3 cores, indicates that a minimum of 5 m of sea-level change occurred during flooding of the upper parasequence.

Parasequences in the Stewart Pool

In contrast to the regression-dominated relative sea-level curves recorded in carbonate successions (Fig. 72), correlative estuarine siliciclastic successions may record both symmetrical and transgression-dominated relative sea-level curves (Figs. 53 & 72). Figure 53 displays the interpreted relative sea-level histories for both estuarine parasequences in the Stewart Pool.

The primary difference between siliciclastic and correlative carbonate relative sea-level profiles is the lack of the transgressive portion of the curve in the carbonate sequences. Thick transgressive successions in carbonates are replaced by basal condensed sections deposited when the rate of sea-level rise was greater than carbonate accumulation rates. Four factors contributed to the preservation of the transgressive portion of the profile in the Stewart Pool.

First, estuarine siliciclastics were deposited and preserved at the up-depositional-dip terminus of sequence *1* strata. Siliciclastics are ponded at the coastline during transgression (Heckel, 1990; Wignall, 1991) and are left stranded at the maximum extend of marine

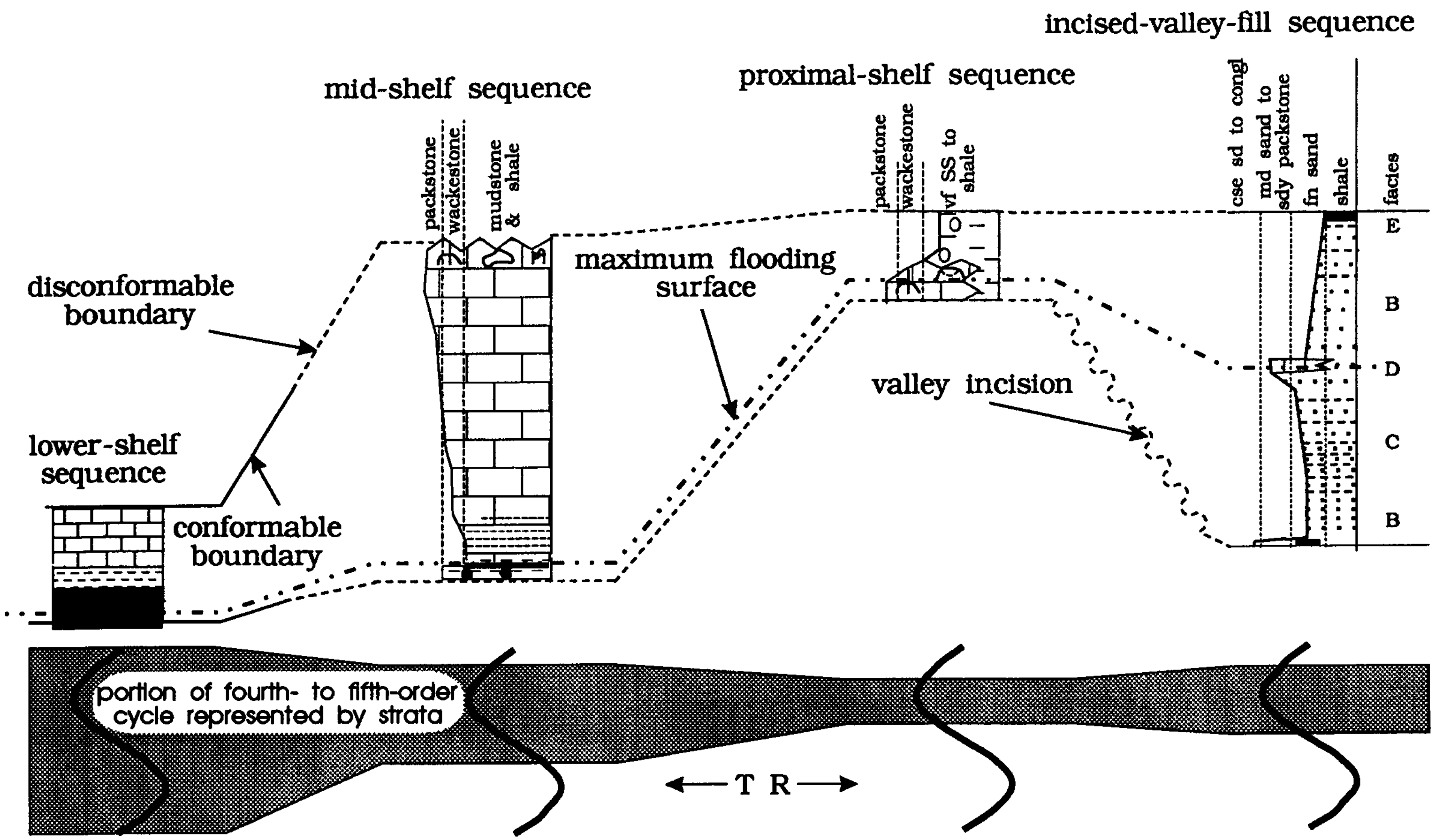

Fig. 72 Comparison of "Gray group" carbonate sequences to idealized incised valley-fill siliciclastic sequence in the Stewart Pool.

inundation. The maximum extent of marine inundation occurs after the maximum rate of sea-level rise at the turn-around point of the sea-level curve. Consequently, estuarine sedimentation began when the rate of sea-level rise was slowing and was not sufficient to overwhelm siliciclastic sedimentation.

Second, siliciclastic sedimentation is not affected by water chemistry, light and other environmental factors that may adversely effect carbonate deposition during transgressions. Reduced clarity of the water column and nutrient excess do not effect siliciclastic sedimentation.

Third, at the maximum extent of marine inundation, the coastline was onlapping the sub-Pennsylvanian unconformity surface. Onlapping the unconformity surface provided both accommodation space (within incised valleys) and a source of sand (the Ste. Genevieve Limestone).

Fourth, sedimentation rates in coastal estuaries may be considerably faster than those of shelf carbonates (e.g. Enos, 1990) and may be more capable of keeping up with rising sea level. Rapid sedimentation rates in estuaries are a result of the focusing of sediments into one location by tidal, marine and fluvial processes.

These four characteristics of estuarine deposition result in the preservation of a relative sea-level history with greater fidelity than can be accomplished in an equivalent carbonate-dominant environments.

The upper parasequence displays a transgression-dominant relative-sea-level profile in contrast to both the symmetrical profile of the lower parasequence and the regressive-dominant profile of correlative carbonates. The transgressive-dominant profile, in the Scott #4-8 core, reflects preservation of a deepening-upward siliciclastic succession. However, since this parasequence is capped by a sequence boundary, it is plausible that either a basinward shift in facies occurred before siliciclastic progradation could take place, or that pre-*k* erosion removed the strata that would have recorded a regression.

Timing of estuarine versus shelf sedimentation.

Proximal-shelf carbonates probably began accumulating about the same time siliciclastic sediments were being ponded in the estuaries (Fig. 69). Mid-shelf carbonates probably began accumulating slightly later (Figs. 70 & 71), when water clarity and chemistry became more favorable to marine organisms. Lower-shelf carbonates probably did not begin to accumulate until well after estuarine deposition ceased and base level dropped to the point where the lower-shelf environment was above the pycnocline and in the euphotic zone. Estuarine siliciclastics may be considerably thicker than correlative carbonates, despite shorter duration of deposition because of locally higher sedimentation rates (Enos, 1990) and ample accommodation space within incised valleys.

CHAPTER SIX

"GRAY GROUP" SANDSTONES IN THE EASTERN HUGOTON EMBAYMENT

Minneola Pool Area

Introduction

An investigation of the Minneola Pool area was undertaken to determine the stratigraphic position of productive sandstones there. Clark (1987) suggested that the productive sandstones are of Morrowan age. He further suggested the Morrow sandstones lie conformably below the Atokan "Thirteen Finger" lime. This investigation presents data that indicates that productive sandstones are correlative with lower "Gray group" carbonates in sequences *l* and *k*.

General Geology.- The Minneola Pool area lies in the eastern Hugoton embayment about fifty miles southeast of the Stewart Pool (Fig. 1). An area including township 29 south, ranges 24 and 25 west, in Ford County, and township 30 south, ranges 24, 25 and 26 west, in Clark and Meade Counties was mapped from available scout tickets and wireline logs (Fig. 73). Core data was available for study in only two wells, a dry hole and a producer. The dry hole contained no

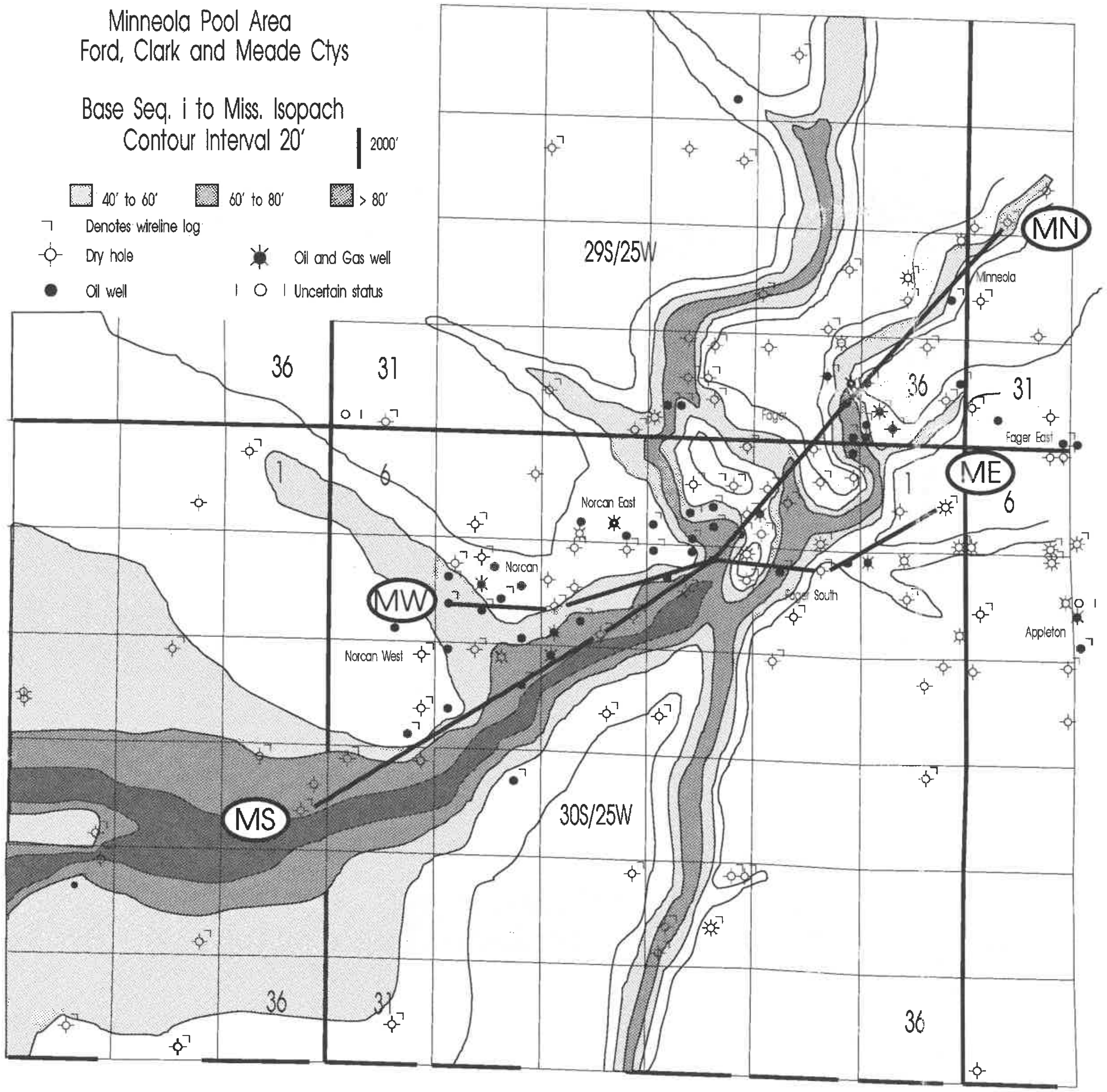

Fig. 73 Minneola Pool area isopach map from base of sequence i to Mississippian.

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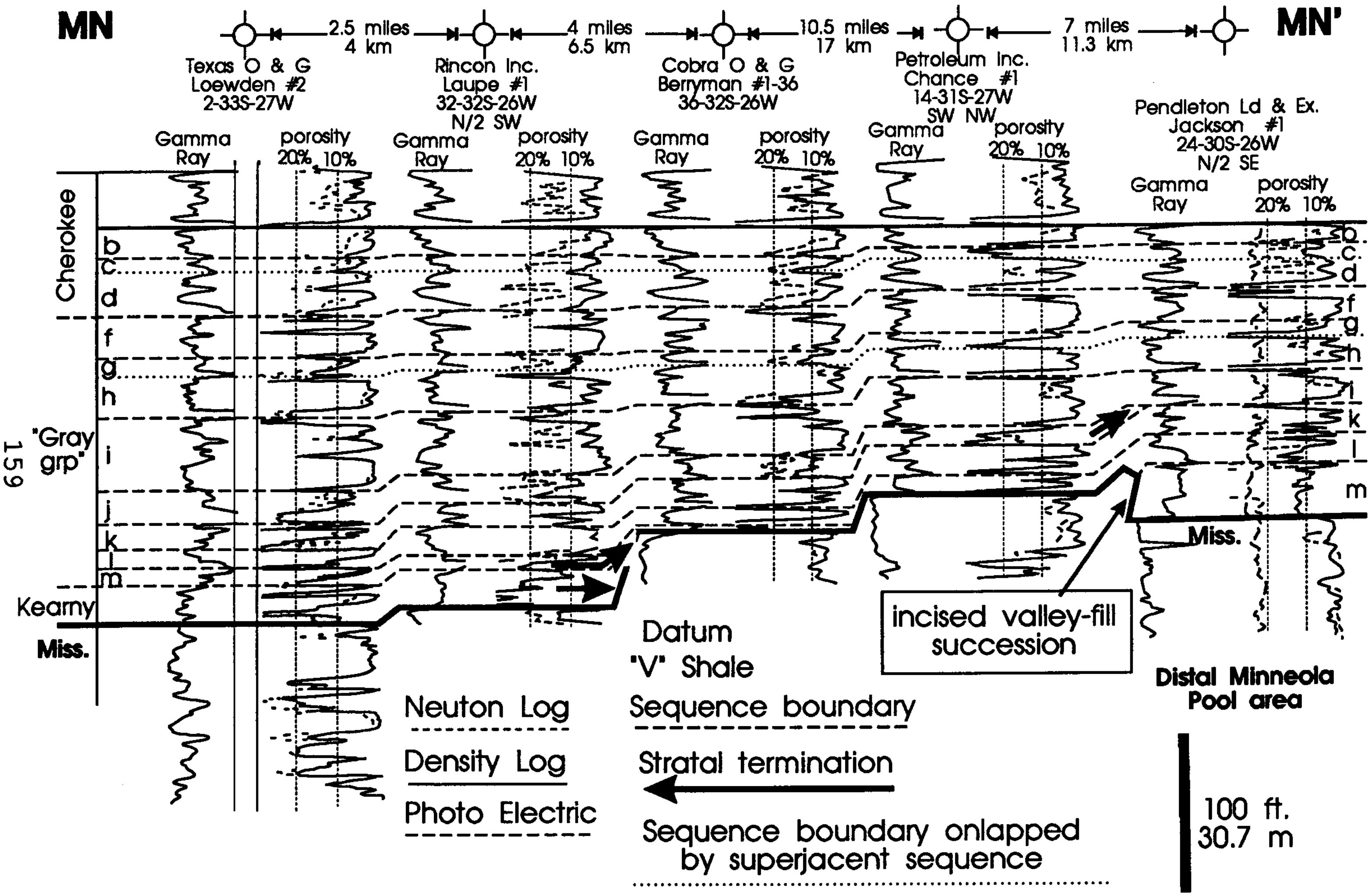

Fig. 74 Cross section MN-MN. See Fig. 2 for location.

reservoir-quality sandstone, and all sandstone had been removed from the core of the producing well. Although these cores are helpful in identifying "Gray group" sequence boundaries, they do not provide data to determine the specific depositional environments of producing sandstones in the area.

Cross sections MN-MN′ (Fig. 74), I1-I1′, and I2-I2′ (Fig. 34 & 35) display the correlation of "Gray group" sequences from cross section A-A′ northeastward to the Minneola Pool area (Fig 2). Cross sections MN-MS (Fig. 75) and MW-ME (Fig. 76) reveal in more detail the gradational change from "Gray group" shelf-carbonate deposition to contemporaneous siliciclastic deposition.

An isopach map from the base of sequence *i* to the Mississippian reveals the topography upon which "Gray group" sequences *m-k* were deposited (Fig. 73). The isopach map, based solely upon data from wireline logs and scout tickets, indicates a complex pattern of narrow elongate thicks that trend either NE-SW or NW-SE. These elongate thicks probably represent paleovalleys incised into the underlying Ste.Genevieve Limestone. Reflection seismic data indicates that most Minneola area sandstones are located within paleovalleys incised into underlying Mississippian carbonates (Clark, 1987). Unfortunately, the lack of marker beds within the Mississippian make it

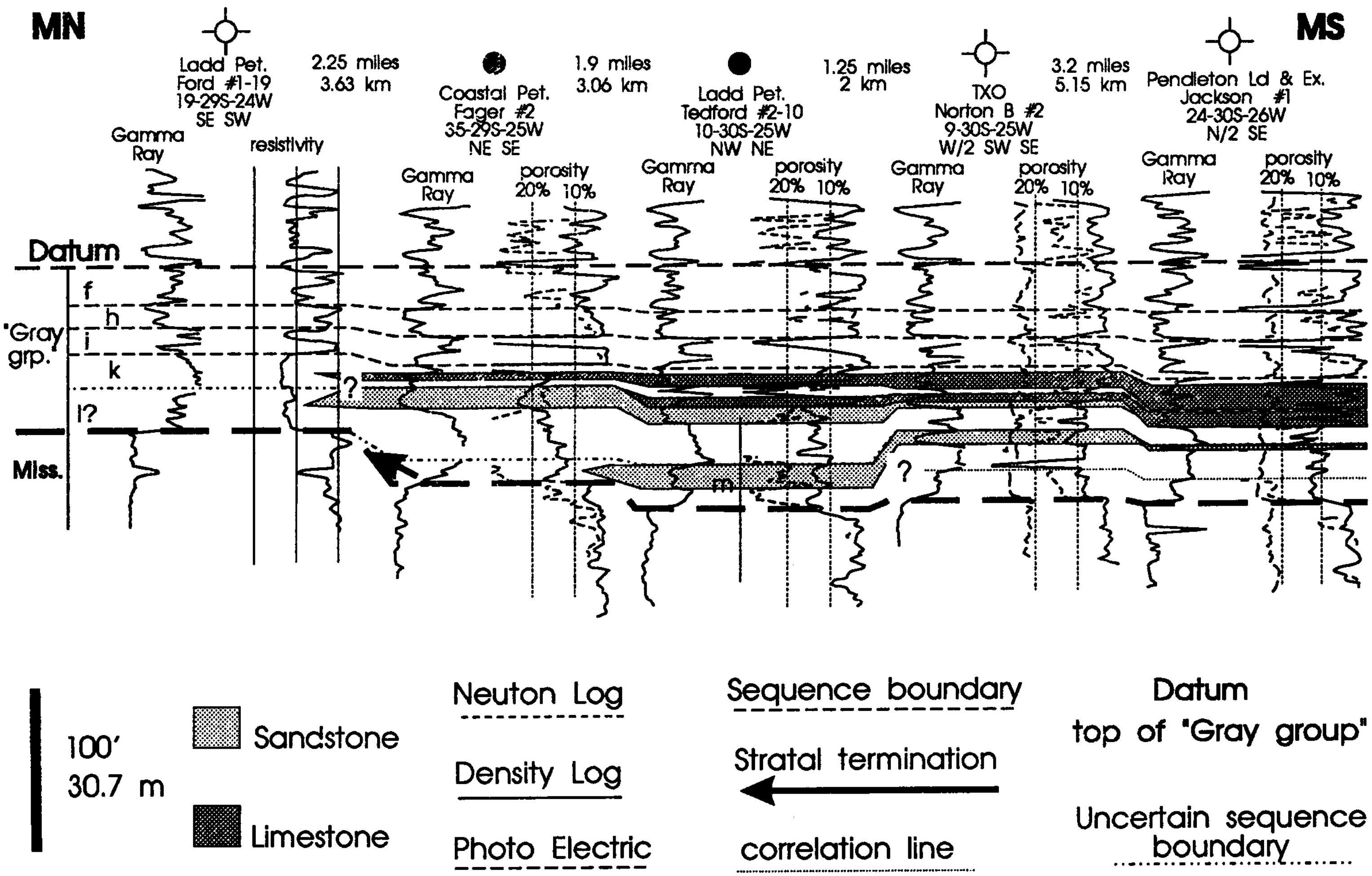

Fig. 75 North-south cross section through Minneola Pool area. See Fig. 73 for location.

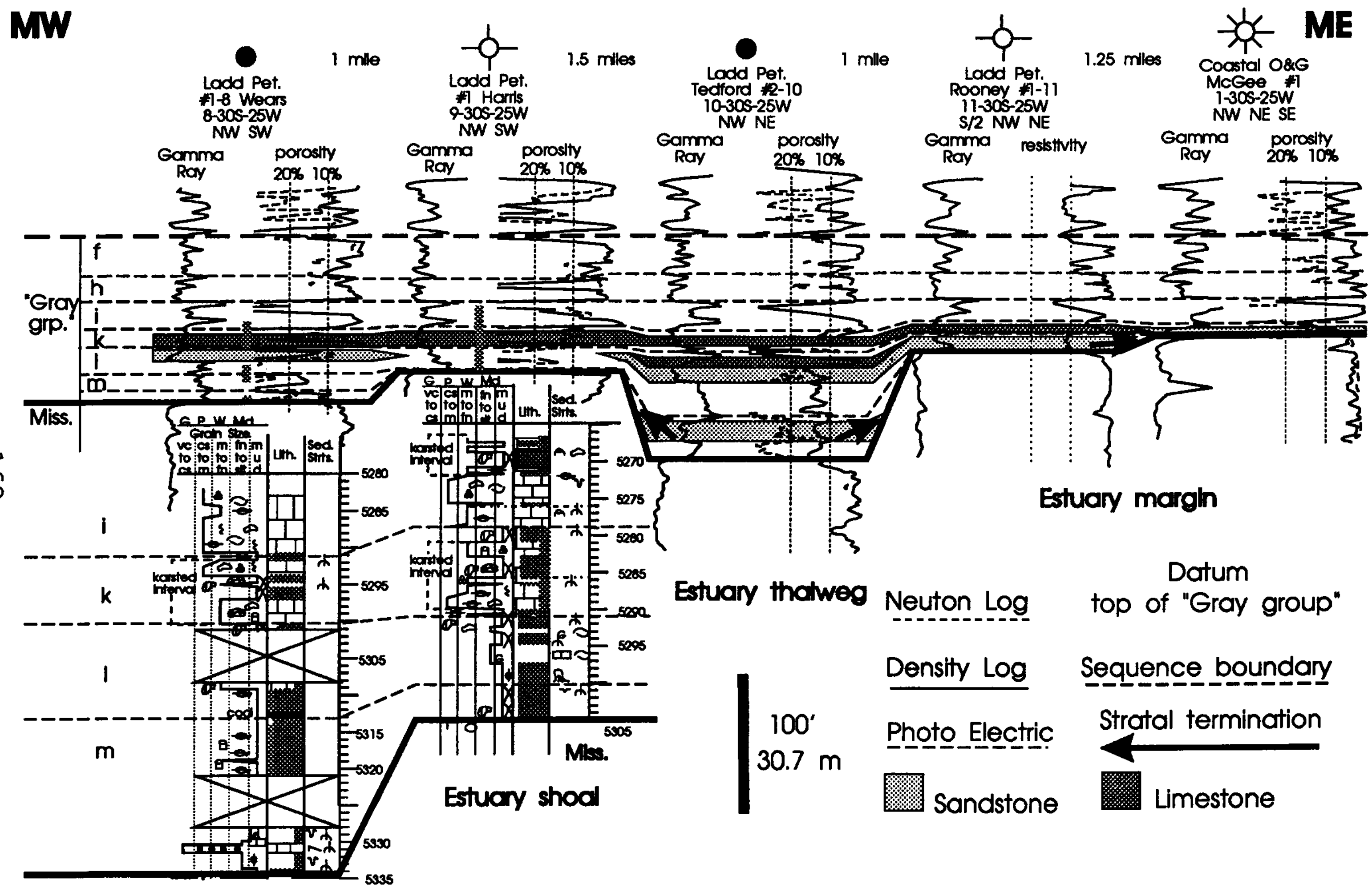

Fig. 76 East to west cross section through Minneola Pool area. Location of cross section on Fig. 73. Core key on Fig. 29.

impossible to determine from wireline logs the magnitude or lateral extent of truncation prior to "Gray group" deposition.

Observations from cross-section MW-ME

Cross section MW-ME (Fig. 75) runs east-west through the only two wells with core control. Sequence boundaries identified in these cores were correlated to wireline logs and extrapolated along the length of the cross section.

Sequence *1* sandstone is oil productive in the Ladd #1-8 Wears at the west end of the cross section (Fig. 75). However, this sandstone thins northeastward into the Ladd #1 Harris where it is an unproductive bioturbated, glauconitic, shaly, limey, very fine sandstone and siltstone with root traces at the top. This facies transition suggests that productive sequence *1* siliciclastics grade laterally, and up depositional dip, into low-energy upper-intertidal sandstones. Sequence *1* thickens from 10 ft. in the #1 Harris to 32 ft. in the Tedford #2-10 (Fig. 75). This increase in thickness probably results from deposition in a deeper part of a paleovalley. In the Tedford #2-10, sequence *1* consists of a coarsening upward siliciclastic unit capped by a limestone. The wireline-log signature of sequence *1* in the Tedford #2-10 looks very similar to that of the #1 Brinkmeyer in the Stewart estuary (Fig. 46). The vertical facies transition through sequence *l* in the #2-10 Tedford is interpreted to represent a deepening upward transition from coastal-estuarine siliciclastics into open marine carbonates.

Further east of the Tedford #2-10, sequence *l* thins to 8 ft in the Rooney #1-11 where it consists of about 4 ft of non-productive shaly sandstone. The unproductive facies in the Rooney #1-11 is probably similar to facies in the # 1 Harris. East of the Rooney #1-11, sequence *l* onlaps the sub-Pennsylvanian unconformity surface. This cross-section also suggests that the 3 ft of gas sandstone in the McGee #1 at the east end of the cross section is the updip siliciclastic equivalent of sequence *k* carbonates.

Observations from cross section MN-MS

Cross section MN-MS runs along the axis of one of the "thicks" on Figure 73 and illustrates that "Gray group" carbonates in sequences *m-k* grade landward into contemporaneous siliciclastic units. On the north end of the cross-section, in the Ford #1-19, no carbonates are present below sequence *i*. However, at the south end of the cross-section, in the #1 Jackson, 25 ft of limestone underlies sequence *i*. Despite the uncertainty in the correlation of sequence boundaries along this cross section, it appears that carbonates from younger sequences step landward over carbonates from older sequences before grading landward into contemporaneous siliciclastics. This pattern of intrasequence and intersequence facies changes results in the en echelon stacking pattern of "Gray group" sandstones on the pre-Pennsylvanian unconformity surface, and is consistent with the retrogradational nature of "Gray group".

Interpretation of Minneola Pool area Sandstones

Wireline-log cross-sections indicate that "Gray group" carbonates grade landward into reservoir-quality sandstones in the Minneola Pool area. Despite a lack of core control, Minneola Pool sandstones are interpreted to have been deposited in an estuary based upon analogy with the Stewart estuary. The Minneola Pool area has many characteristics in common with the Stewart estuary: 1) both contain sandstones that grade basinward into open marine carbonates, 2) in both areas sandstones are confined to a funnel-shaped low on the Mississippian unconformity surface that is surrounded on three sides by positive areas and trends normal to depositional strike of "Gray group" sequences, 3) both areas contain incised valleys within the funnel-shape low, 4) in both areas the sandstones rest unconformably upon the sandy Ste. Genevieve Limestone of Mississippian age, and 4) sandstones in both areas belong to the "Gray group".

Summary of "Gray Group" Sandstone Deposition

Sequence stratigraphic setting of "Gray group" sandstones

Reservoir-quality sandstones investigated in this report are located at the landward edges of fourth- to fifth-order depositional sequences that are part of a transgressive sequence-set. Transgressive sequence-sets are deposited when the rate of third-order sea-level rise is at a maximum and dominates fourth- to fifth-order sea-level cycles (VanWagoner, 1991). During deposition of sequences in the transgressive sequence-set, the creation of accommodation space is maximized and fourth- to fifth-order sea-level drops are minimized. These circumstances result in minimal post-depositional erosion of sequences prior to subsequent inundation, and in the preservation of proximal-shelf sandstones.

Depositional Environments of "Gray group" sandstones

"Gray group" sandstones are preserved within paleovalleys that have been incised into Mississippian carbonates. Submarine and shoreface erosion broadened incised valleys into estuaries at the maximum landward extent of "Gray group" sequences.

Reservoir-quality sandstones accumulated in estuaries due to a combination of two factors including: 1) presence of accommodation space within incised paleovalleys and 2) due to the focusing of sandstone deposition by tidal currents and waves.

Summary of the Stratigraphy of "Gray Group" Sandstones

Younger "Gray group" sequences overstep older ones and onlap the sub-Pennsylvanian unconformity surface toward the Central Kansas uplift. This results in the en echelon distribution of successively younger "Gray group" sandstones northeastward across the eastern Hugoton embayment. The proximity of these sandstones to the sub-Pennsylvanian unconformity surface has led most workers to correlate "Gray group" sandstones of different sequences into a single basal Pennsylvanian sandstone and classify them as Morrowan in age. However, detailed wireline correlations have established that the productive sandstones in this report can be correlated basinward into temporally equivalent "Gray group" carbonate sequences. Investigation of the Minneola Pool area also revealed that, locally, proximal siliciclastics from three "Gray group" sequences may be shingled and partially overlap vertically.

Distribution of "Gray Group" Sandstones in the Eastern Hugoton Embayment

"Gray group" sandstones should be best developed and preserved in estuaries that formed within localized incised valleys near the updip terminus of each "Gray group" sequence that onlaps the sub-Pennsylvanian unconformity surface. Sandstones studied in this investigation were developed where sequences onlap the sandy Ste. Genevieve Limestone, which may have acted as a local source of sand.

The development of reservoir-quality sandstone within each sequence is a function of the depositional dynamics unique to each estuary. Investigations of the Stewart Pool indicate that the best reservoir-quality sandstones accumulated on intertidal sand-flats in estuarine environments. Detailed geologic mapping using cores and sophisticated wireline logs will be necessary in order to determine where within the estuarine environment each producing well is located.

CHAPTER SEVEN

CONCLUSIONS

1. The "Gray group" is correlative with the "Thirteen Finger" lime in Oklahoma and is probably, at least partially, Atokan in age. It lies with slight disconformity above the Kearny Formation (probable Morrowan-age rocks) in the eastern Hugoton embayment. "Gray" and Cherokee Groups form one relatively continuous body of carbonate-dominated strata which overstep the Kearny and successively onlap the sub-Pennsylvanian unconformity surface toward the Central Kansas uplift. "Gray group" rocks are conformable with younger Cherokee Group strata in Seward County but become slightly disconformable (by depositional hiatus) on the flanks of the Central Kansas uplift.

2. Lower Middle Pennsylvanian strata in the Hugoton embayment consist of thirteen fourth- to fifth- order sequences from the "V" shale down to the Kearny Formation. Sequences onlap the sub-Pennsylvanian unconformity surface or subjacent sequences from the lower Hugoton shelf toward the Central Kansas uplift.

3. Sequences are sigmoidal in shape. Mid-shelf sequences thin by downlap into the lower shelf and many thin by toplap onto the proximal shelf.

4. Lower-shelf sequences (10 to 30 ft. thick) are

conformable and sequence boundaries are picked at the tops of thin limestones or the base of black shales.

5. Mid-shelf sequences (10 to 120 ft. thick) are slightly disconformable and sequence surfaces are identified by evidence of subaerial exposure upon subtidal rocks and a change in parasequence stacking patterns.

6. Proximal sequences (up to 15 feet thick) are disconformable and characterized by thin karsted limestones or siliciclastic strand or estuarine units and thick soil profiles (up to 10 feet thick). Proximal sequences eventually merge landward into one or more exposure surfaces.

7. Lower-shelf sequences differ from typical Kansas cyclothems in that they have no middle limestones or outside shales. Mid-shelf sequences are similar to cyclothems except the middle limestone equivalents are exceedingly thin and outside shales are very poorly developed. Proximal sequences are composed of thin carbonate or siliciclastic units equivalent to mid-shelf or lower-shelf core shales and are capped by well-developed outside shales.

8. Thickness and facies distribution within lower Middle Pennsylvanian strata were affected by the superposition of at least three scales of relative sea-

level changes. Sequences described in this report are equivalent to fifth- or fourth-order cycles. The changes in the character of fifth- or fourth-order cycles within "Gray" and Cherokee Group strata indicate the presence of a third-order cycle. Despite the third-order fall in relative sea-level, onlap may have continued onto the Central Kansas uplift and would suggest that a larger order relative sea-level rise also affected lower Middle Pennsylvanian deposition. The combined frequencies of cycles resulted in the retrogradational nature of the lower Middle Pennsylvanian succession in the eastern Hugoton embayment.

9. Transgressive and highstand sequence-sets were developed during a third-order relative sea-level cycle superimposed upon the second-order relative sea-level rise. Four sequences (*a,c,e* and *g*) onlap subjacent sequences and formed during a lowstand or late highstand sequence-set when accommodation space was lacking on the shelf.

10. Oil-productive basal Pennsylvanian sandstones in the Stewart Pool (Finney County) and Minneola Pool area (Clark, Ford and Meade Counties) belong to the "Gray group" and are not Morrowan in age. These sandstones are younger than Kearny sandstones and should not be mapped as one unit with any Kearny sandstones.

11. "Gray group" sandstones lie at the updip terminus of "Gray group" sequences and were in deposited in estuaries. Estuaries were formed in paleovalleys incised into underlying Mississippian units.

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APPENDIX A:

Wells Shown on Stewart Pool Maps

Operator- Lease- well No.- Township/Range/Section- spot location

BENNETT&ROBERTS COATCUM 1 22.S/30.W/30 SW/SW/SW

WOOSLEY SAMUELSON 1 22.S/30.W/31 SE/SW

MACK FOSTER 1 22.S/30.W/31 NE/SE

APPELMAN TERKELL 1 22.S/31.W/19 SE/SE/SE/NW

MCKELVY TREKELL 2 22.S/31.W/19 NW

NO PUMP GINGRICH 1 22.S/31.W/20 SE/SE/SE/NW

COOP REF SONDEREGGER 1 22.S/31.W/21 NE/NE/NE

COOP REF SONDEREGGER 2 22.S/31.W/21 NW/SE/NE

JONES&PELLOW SCOTT 1 22.S/31.W/22 SE

CARTER RUSSELL 1 22.S/31.W/22 NE/NW/NW

MCKELVY SCOTT 1-A 22.S/31.W/22 SW

T-BIRD HAWES 1 22.S/31.W/24 SW/NW

JONES&PELLOW STUCKY-GRABER 1 22.S/31.W/26 NW/SW

MCKELVY SCOTT 1 22.S/31.W/27 NW

MCKELVY JOYCE 1-18 22.S/31.W/28 NW

MCKELVY MEAIRS 1 22.S/31.W/28 NE

SHELL GINGERICH 1 22.S/31.W/29 NE/SW/SW

MCKELVY TREKELL 1 22.S/31.W/30 NW

TRUE LEWIS 32-1 22.S/31.W/32 NE

NEWMANN LEWIS 1 22.S/31.W/32 W2/E2

NARCO CARR 35-1 22.S/31.W/35 1250FS/4230FE

ZENITH LINDER 1 22.S/32.W/24 SE/SW

F&M OIL CONCANNON 1 1 23.S/30.W/3 SW/SW

TEXACO DAVIS 1 23.S/30.W/3 SW/NE

NORTH AM. RES. CO. WILEY 5-1 23.S/30.W/5 330FW/330FS

PET-EX BOYD 1 23.S/30.W/5 NW/NW

BEREN HAAG A-1 23.S/30.W/6 SW/SE

WOOLSEY HAAG 3 23.S/30.W/6 SE/NE

WOOLSEY HAAG 1 23.S/30.W/6 NW/SW/NE

NAT.COOP REF STEWART A-1 23.S/30.W/6 NE/SW/NW

DAVIDOR HAAG 1 23.S/30.W/6 NW/NE/SW

WOOLSEY HAAG 2 23.S/30.W/6 N2/NW/SE

SHARON RES. BULGER 7-7 23.S/30.W/7 3135FS/990FE

SHARON RES BULGER 7-6 23.S/30.W/7 2310FS/2310FE

SHARON RES. BULGER 7-5 23.S/30.W/7 3300FS/2310FE

SHARON RES. BULGER 7-2 23.S/30.W/7 2625FS/3960FE/

SHARON RES. BULGER 7-1 23.S/30.W/7 3300FS/4950FE/

SHARON RES BULGER 7-3 23.S/30.W/7 660FS/3960FE/

SHARON BULGER 7-4 23.S/30.W/7 3330FS/3630FE/

CHALLENGER BULGER 1 23.S/30.W/7 NW/NW

SRI BULGER 7-9 23.S/30.W/7 660FS/330FE

KEWANEE HAAG 1 23.S/30.W/8 NE/NE

SHARON HAAG 8-1 23.S/30.W/8 4950FS/4950FE/

CHIEF HAAG 1-8 23.S/30.W/8 3630FS/4950FE

CHIEF HAAG 2-8 23.S/30.W/8 NW

NORTH AM RES CO HAFLICK 1-8 23.S/30.W/8 330FS/4950FE

SHARON HAFLICH 1 23.S/30.W/8 660FS/4950FE

NARCO HAFLICH 8-3 23.S/30.W/8 SW/SE

NARCO HAFLICH 8-3 23.S/30.W/8 SE/SE

CHIEF WILEY 1-9 23.S/30.W/9 SW/SW/SW

PUBLISHERS PET MILLER 1 23.S/30.W/16 SE/SE/SW

NORTH AM RES CO HERBERT 17-1 23.S/30.W/17 NW/NW

NARCO HERBERT 17-2 23.S/30.W/17 4620FS/3300FE

SHARON RAMSEY 18-2 23.S/30.W/18 4620FS/1980FE

SHARON RAMSEY 18-1 23.S/30.W/18 4620FS/660FE

ELY ELY 1 23.S/30.W/18 NE/SE

TXO TREKELL 1 23.S/31.W/1 S2/SE/SE

DAVIDOR TEKELL 1 23.S/31.W/1 SW/SE

DAVIDOR WARNER 1 23.S/31.W/1 SW/NE

PLAINS JANOF 1 23.S/31.W/1 SE/SE/NE

SHARON NELSON 2-4 23.S/31.W/2 1320FS/4620FE

SHARON NELSON 2-3 23.S/31.W/2 495FS/4290FE

SHARON NELSON 2-2 23.S/31.W/2 1320FS/3630FE

SHARON NELSON 2-1 23.S/31.W/2 330FS/2970FE

SHARON CARR 2-2 23.S/31.W/2 1650FS/2310FE

SHARON CARR 2-1 23.S/31.W/2 330FS/1980FE

SHARON CARR 2-3A 23.S/31.W/2 3700FS/1085FE

SHARON CARR 2-4 23.S/31.W/2 SW/NW/NE

SHARON SHERMAN 3-1 23.S/31.W/3 660FS/330FE

SHARON SHERMAN 3-2 23.S/31.W/3 660FS/1650FE

SHARON SHERMAN 3-3 23.S/31.W/3 330FS/2970FE

SHARON SHERMAN 3-4 23.S/31.W/3 3300FS/4950FE

SHARON SHERMAN 3-5 23.S/31.W/3 165FS/4950FE

SHARON SHERMAN 3-6 23.S/31.W/3 330FS/3795FE

SHARON SHERMAN 3-8 23.S/31.W/3 1000FS/950FW

SHARON SHERMAN 3-9 23.S/31.W/3 500FS/2660FE

SHARON SCOTT 4-1 23.S/31.W/4 330FS/660FE

SHARON SCOTT 4-2 23.S/31.W/4 330FS/2310FE

SHARON SCOTT 4-3 23.S/31.W/4 660FS/3300FE

SHARON SCOTT 4-4 23.S/31.W/4 1320FS/2970FE

SHARON TVC 4-1 23.S/31.W/4 4950FS/3960FE

SHARON SCOTT 4-5 23.S/31.W/4 1500FS/4180FE

SHARON SCOTT 4-6 23.S/31.W/4 2310FS/4950FE

SHARON SCOTT 4-7 23.S/31.W/4 1550FS/1980FE

SHARON SCOTT 4-8 23.S/31.W/4 2250FS/3430FE

SHARON BECKER 5-1 23.S/31.W/5 1200FS/330FE

SHARON BECKER 5-2 23.S/31.W/5 1400FS/330FE

SHARON TVC 5-1 23.S/31.W/5 1320FS/3960FE

SRI BECKER 5-3 23.S/31.W/5 1800FS/330FE

M&L TREKEL 1 23.S/31.W/6 NW/NW/NW

JONES&PELLOW VINDUSKA 1 23.S/31.W/7 SW

SHARON HAAG 8-1 23.S/31.W/8 4950FS/4950FE

APACHE SHERMAN 1 23.S/31.W/8 SE

NO AM RES HOPPER 9-1 23.S/31.W/9 2000FS/330FE

NO AM RES HOPPER 9-2 23.S/31.W/9 1250FS/1320FE

NO AM RES PAULS 9-1 23.S/31.W/9 4950FS/330FE

NO AM RES PAULS 9-2 23.S/31.W/9 4080FS/1575FE

NO AM RES PAULS 9-3 23.S/31.W/9 4950FS/2310FE

NO AM RES PAULS 9-4 23.S/31.W/9 4480FS/2990FE

SHARON MEYER 10-1 23.S/31.W/10 4950FS/2190FE

SHARON MEYER 10-3 23.S/31.W/10 4785FS/4455FE

SHARON MEYER 10-4 23.S/31.W/10 5115FS/990FE

SHARON MEYER 10-2 23.S/31.W/10 4785FS/3300FE

SRI MEYER 10-5A 23.S/31.W/10 4259FS/2574FE

SHARON SHERMAN 7 23.S/31.W/11 4620FS/4290FE

SHARON SHERMAN 2 23.S/31.W/11 3960FS/1650FE

SHARON SHERMAN 5 23.S/31.W/11 4620FS/3630FE

SHARON SHERMAN 1 23.S/31.W/11 3960FS/330FE

SHARON SHERMAN 3 23.S/31.W/11 4620FS/2310FE

SHARON SHERMAN 4 23.S/31.W/11 4785FS/990FE

SHARON SHERMAN 6 23.S/31.W/11 3145FS/660FE

DAVIDOR SHERMAN 1 23.S/31.W/11 NE/SE

HADSON PET SHERMAN 2-11 23.S/31.W/11 330FS/330FW

HADSON SHERMAN 1-11 23.S/31.W/11 2310FN/2310FE

BEREN HAAG 3 23.S/31.W/12 3300FS/330FE

BEREN MACKEY 4 23.S/31.W/12 3960FS/4950FE

BEREN MACKEY 3 23.S/31.W/12 NE/NW

BEREN MACKEY 6 23.S/31.W/12 3960FS/3960FE

BEREN MACKEY 5 23.S/31.W/12 4620FS/4950FE

BEREN HAAG 4 23.S/31.W/12 3795FS/2310FE

BEREN HAAG 5 23.S/31.W/12 4115FS/1320FE

DAVIDOR HAAG 1 23.S/31.W/12 NE/NE

DAVIDOR HAAG 2 23.S/31.W/12 NW/NE

DAVIDOR HAAG 3 23.S/31.W/12 NW/SE

DAVIDOR MACKEY 1 23.S/31.W/12 SE/NW

DAVIDOR MACKEY 2 23.S/31.W/12 NW/SW

DAVIDOR SLOTHOWER 1 23.S/31.W/14 NE/NE

MCBRIDE DAVIS-CAMBELL 1 23.S/31.W/15 NW

TRUE CAMPBELL 15-1 23.S/31.W/15 E2

RIVIERA ADAMSON 1-16 23.S/31.W/16 NE

CATLETT ADAMSON 1 23.S/31.W/16 SE

MOBIL BITTIKER 1 23.S/31.W/17 NW

MCKELVY HUELSKAMP 17 23.S/31.W/17 50N/SE

MCKELVY SOMERS 1 23.S/31.W/17 SW

BMG BOYD 1 23.S/31.W/18 SE

GRAHMN-MICHEALS RUSSELL 1 23.S/31.W/18 NW

TRUE BOYD 1 23.S/31.W/18 SE

MCKELVY RUSSELL 1B 23.S/31.W/18 150FN/1320FW

BMG BOYD 2-18 23.S/31.W/18 N2/N2/SE

MCKELVY MCANARVEY 1 23.S/31.W/19 SE

PET INC JONES 1-HI 23.S/31.W/19 NW/NE

HUGOTON SEEDLE 1-20 23.S/31.W/20 1320FS/3960FE

RIVIERA HAZELTON 1-21 23.S/31.W/21 NW

SUN HAZELTON 1 23.S/31.W/21 SE/NW

MCKELVY MERRILL 22 23.S/31.W/22 SE

DAVIDOR TATE 1 23.S/31.W/23 NE/NW

MCKELVY STEVENS 27 23.S/31.W/27 SE

AM. ENERGIES DECHANT 1 23.S/31.W/28 1980FS/1980FE

MCKELVY DECHANT 28 23.S/31.W/28 SE

BEREN HUELSKAMP 1 23.S/31.W/28 510FN/660FE/SW

SINCLAIR RUCKER 1 23.S/31.W/28 NW

ZENITH DECHANT B-1 23.S/31.W/28 W2/SW/NE

ZENITH LIVELY 1 23.S/31.W/28 NE/NW

PET. INC. RUCKER 2 23.S/31.W/28 760FS/760FW/NW

ZENITH RUCKER 1 23.S/31.W/28 SW/NW

NO. AM. RES. CO DECHANT 28-1 23.S/31.W/28 2100FS/660FE

MCKELVY HATFIELD 1 23.S/31.W/29 NE/SE

ZENITH MERRILL 1 23.S/31.W/29 NE/NE/

MCKELVY SPIKES 29 23.S/31.W/29 NW

CONTINENTAL ENG BRINKMEYER 1 23.S/31.W/30 3960FS/3960FE

MCKELVY MARTIN 1 23.S/31.W/30 SW

APPENDIX B

Wells Shown in Minneola Pool Area

Operator- Lease- well No.- township/range/section- spot location

PICKRELL DRLG FORD 1-A 29.S/24.W/19 330FS/330FW

PICKRELL DRLG WEDDLE 1-A 29.S/24.W/19 2310FS/1320FE

LADD PET FORD 1-19 29.S/24.W/19 660FS/1980FW

LADD PET DENNISTON 1-30 29.S/24.W/30 1980FS/660FW

PICKRELL DRLG DENISTON 1-C 29.S/24.W/30 330FS/1650FE

MURFIN DRLG ROONEY 1-31 29.S/24.W/31 1980FS/330FW

BANKS LEE OIL SHELOR 1 29.S/24.W/31 330FS/330FE

BANKS LEE OIL SHELOR 2-31 29.S/24.W/31 1650FS/990FE

PICKRELL DRLG DUFFORD 1-A 29.S/24.W/32 2310FS/1980FE

MURFIN DRLG GOETZ 1 29.S/25.W/1 60W/SE/SE/SE

WOODS PET BARTLETT 1 29.S/25.W/5 660FS/660FE

THUNDERBIRD DRLG MCCUNE 1 29.S/25.W/14 SE/NW

CHAMPLIN PET DORIS D ROONEY 1 29.S/25.W/15 NW/SE/SE

DEEP ROCK OIL RAYMOND 1 29.S/25.W/21 NW/SW/NW

MITCHELL ENERGY DANIELS B 1 29.S/25.W/22 1500FN/1900FW

QUINTANA PET SCHNEIDER 1-22 29.S/25.W/22 3300FS/660FE

CHAMPLIN PET MCCUNE 1 29.S/25.W/25 NE/NE/NE

CHAMPLIN PET MCCUNE /A/ 1 29.S/25.W/25 2310FN/2310FW

CHAMPLIN PET MC CUNE /B/ 1 29.S/25.W/25 1990FS/760FE

CHAMPLIN PET MCCUNE /C/ 1 29.S/25.W/25 1900FS/2310FW

BANKS LEE OIL KOPPES 1 29.S/25.W/26 SE/NE

BANKS LEE OIL ROONEY 1-26 29.S/25.W/26 330FS/1650FE

LADD PET ROONEY 1-26 29.S/25.W/26 1980FS/330FW

PENDLETON LAND & EXPL WILCOXEN 1 29.S/25.W/31
330FS/2530FE

LADD PET HALL A W 1 29.S/25.W/33 2173FS/330FW

TXO PROD HARRIS "P" 1 29.S/25.W/33 330FS/660FE

LEBEN DRLG & ROONEY BRO MCCONNEL 1 29.S/25.W/34 NW/NE

BANKS LEE RATZLAFF OWWO 29.S/25.W/34 NW NE

BANKS OIL WYATT 1 29.S/25.W/34 N2/NE/NW

BANKS OIL WYATT 1-34 29.S/25.W/34 1650FS/990FE/SW

TXO PROD WYATT /A/ 1 29.S/25.W/34 1650FS/990FW

THUNDERBIRD DRLG OSHLO 1-34 29.S/25.W/34 1980FS/1980FE

PHILLIPS OIL RATZLAFF 1 29.S/25.W/34 2310FN/2310FE

TXO PROD WYATT "A" 2 29.S/25.W/34 990FS/330FW

TXO PROD WYATT /A/ 3 29.S/25.W/34 2310FN/1980FW

COASTAL O&G FAGER 1 29.S/25.W/35 330FS/330FE

RAINS & WILLIAMSON OIL ASKEW 1 29.S/25.W/35 990FE/330FN

BANKS LEE OIL T L C 1 29.S/25.W/35 NW/NW

COASTAL O&G FAGER 2 29.S/25.W/35 NE/SE

COASTAL O&G J ASKEW 2-35 29.S/25.W/35 660FS/1650FE/NE

SPINES EXPL ASKEW 3 29.S/25.W/35 330FS/495FE/NE

LADD PET C S SHELOR 1 29.S/25.W/36 330FS/330FW

PICKRELL DRLG AMY /A/ 2 29.S/25.W/36 2310FN/330FW

PICKRELL DRLG CHRISTIAN CHURCH 1-A 29.S/25.W/36
1650FS/990FW

PICKRELL DRLG AMY UNIT 3 29.S/25.W/36 800FS/1650FW

BANKS OIL OSHLO 1-36 29.S/25.W/36 2173FN/330FE

PICKRELL DRLG AMY UNIT 4 29.S/25.W/36 2310FS/990FE

BANKS LEE OIL SHELOR 1-36 29.S/25.W/36 990FS/330FW

PICKRELL DRLG CANNON 1-A 29.S/25.W/36 4950FS/1980FE

TXO PROD HUFF "A" 1 30.S/24.W/6 330FS/990FE

TXO PROD MCCONNELL "B" 1 30.S/24.W/6 330FN/330FE

PICKRELL DRLG OSHLO 1-B 30.S/24.W/6 330FS/4950FE

TRANS PACIFIC OIL MCCONNELL 1 30.S/24.W/6 4950FS/990FE

PICKRELL DRLG OSHLO 1-A 30.S/24.W/7 330FN/940FE

MURFIN DRLG PITTMAN 1-7 30.S/24.W/7 2310FS/4620FE

PICKRELL DRLG OSHLO 4-A 30.S/24.W/7 2970FS/330FE

SPINES EXPL BAIR 1 30.S/24.W/18 600FN/330FW

MURFIN DRLG BAIR 1-18 30.S/24.W/18 4950FS/330FE

MURFIN DRLG BAIR 2-18 30.S/24.W/18 2310FS/330FE

KANSAS CRUDE GOEBEL 16/30.S/24.W/31 SW/SW

PICKRELL DRLG AMY 1-A 30.S/25.W/1 NW/NW/NW

COASTAL O&G MCGEE 1 30.S/25.W/1 990FE/2310FS

SPINES EXPL LAMPE 1 30.S/25.W/1 610FN/660FE/SW

MURFIN DRLG MCGEE 1-1 30.S/25.W/1 330FS/330FE

LADD PET ROONEY 1-2 30.S/25.W/2 NW NW NE

LADD PET ROONEY 2 30.S/25.W/2 4950FS/330FE

MURFIN DRLG ROONEY 1-2 30.S/25.W/2 NE SE NE

MURFIN DRLG ROONEY 2-2 30.S/25.W/2 1980FN/1980FE

LADD PET SCHLICTING 1-2 30.S/25.W/2 330FS/1980FE

MURFIN DRLG ETAL HALL 1-2 30.S/25.W/2 989FN/331FW/SW

MURFIN DRLG HALL 2-2 30.S/25.W/2 2310FS/3630FE

MURFIN DRLG ROONEY "B"1-2 30.S/25.W/2 2970FS/4620FE

MURFIN DRLG HALL B 1-2 30.S/25.W/2 700FS/4949FE

LADD PET PATTON 1 30.S/25.W/3 SE/SE

LADD PET HARRIS E F 1-3 30.S/25.W/3 990FS/330FW

LADD PET FAGER 1-3 30.S/25.W/3 NE/NE/NE

LADD PET HINDMAN 1-3 30.S/25.W/3 1650FS/2173FW

MURFIN DRLG PATTON 1-3 30.S/25.W/3 990FS/1980FE

LADD PET FAGER 2-3 30.S/25.W/3 2310FN/1980FE

SANTA FE ENERGY LENA D BOUCHER 1-3A 30.S/25.W/3
2310FN/2310FW

MURFIN DRLG PATTON 2-3 30.S/25.W/3 1980FS/1980FE

SANTA FE ENERGY BOUCHER LENA D 1-3 30.S/25.W/3
2310FN/2310FW

MURFIN DRLG FAGER 1-3 30.S/25.W/3 2310FN/990FE

LADD PET ETAL HARRIS E F 2-3 30.S/25.W/3 330FS/2310FW

LADD PET PATTON 2-3 30.S/25.W/3 1651FS/331FE

MURFIN GOELLER 1-4 30.S/25.W/4 989FS/1651FE

TXO PROD NORTON "E" 1 30.S/25.W/4 400FS/3380FE

LADD GOELLER 1-4 30.S/25.W/4 330FS/990FE

MURFIN DRLG NORTON 1-4 30.S/25.W/4 990FS/3300FE

LADD PET WEARS 1-5 30.S/25.W/5 675FS/1965FW

BANKS LEE OIL BELDEN 1 30.S/25.W/5 3300FS/330FE

LADD PET CHURCH 1-7 30.S/25.W/7 SW/SE

LADD PET NORTON 1-8 30.S/25.W/8 1400FN/2310FE

LADD PET CANNON 2 30.S/25.W/8 N2/NW/SE

LADD PET WEARS 1 30.S/25.W/8 NW/SW

TEXAS O&G CHURCH 1 30.S/25.W/8 2310FN/2310FW

LADD PET WEARS 2 30.S/25.W/8 SE/NE/SW

LADD PET CANNON 2-8 30.S/25.W/8 330FS/990FE

TXO PROD CHURCH 3 30.S/25.W/8 990FN/2310FW

TXO PROD NORCAN 1 30.S/25.W/8 2310FN/990FE

LADD PET CHURCH 1-8 30.S/25.W/8 1320FN/990FW

LADD CANNON 1-8 30.S/25.W/8 2310FS/1980FE

LADD WEAR 1-8 30.S/25.W/8 SW/NW

LADD PET R L HARRIS 1 30.S/25.W/9 NW/SW

LADD PET R L HARRIS 2 30.S/25.W/9 660FS/660FW

LADD PET ALLEY 1 30.S/25.W/9 1980FN/330FW

LADD PET HARRIS R L 3-9 30.S/25.W/9 1320FS/1980FW

TXO PROD NORTON /B/ 1 30.S/25.W/9 330FN/990FE

TXO PROD NORTON /B/ 2 30.S/25.W/9 660FS/2310FE

MURFIN DRLG NORTON 1-9 30.S/25.W/9 1650FS/660FE

MURFIN DRLG ALLEY 1-9 30.S/25.W/9 4950FS/3630FE

TRANS PACIFIC OIL ALLEY 1 30.S/25.W/9 2970FS/3630FE

LADD PET TEDFORD 1 30.S/25.W/10 NW/NW/NW

MURFIN DRLG TEDFORD 1-10 30.S/25.W/10 330FN/330FE

LADD PET TEDFORD 2-10 30.S/25.W/10 660FN/1980FE

MURFIN DRLG TEDFORD 2-10 30.S/25.W/10 2310FN/1980FW

MURFIN DRLG TEDFORD 4-10 30.S/25.W/10 331FN/2309FW

MURFIN DRLG TEDFORD 3-10 30.S/25.W/10 1650FN/330FE

MURFIN DRLG TEDFORD "B"-1 30.S/25.W/10 3630FS/4290FE

LADD PET LATZKE 1 30.S/25.W/11 1150FN/1320FW

TXO PROD NORTON /C/ 1 30.S/25.W/11 1930FS/2030FW

LADD PET ROONEY 1-11 30.S/25.W/11 990FN/1980FE

JONES VERN ROONEY 1 30.S/25.W/11 4780FS/660FE

SHELL OIL STRATTON 1 30.S/25.W/12 SE/SE/NW

SPINES EXPL ROGERS 1-A 30.S/25.W/12 1205FS/330FE

MURFIN DRLG STATTON 1-12 30.S/25.W/12 4950FS/3120FE

MURFIN DRLG STATTON 2-12 30.S/25.W/12 4850FS/4950FE

MURFIN DRLG SHUMATE 1-13 30.S/25.W/13 3980FS/2100FE

CASTLE-ROCK PROD SHUMATE HAZEL TRUST 1 30.S/25.W/13
4950FS/1150FE

SPINES EXPL CROUCH 1 30.S/25.W/14 330FN/990FW

MURFIN DRLG GOYEN 1-15 30.S/25.W/15 1980FS/660FW

LADD PET FAGER 1-16 30.S/25.W/16 495FN/495FW/NW

SUN OIL & GENERAL CRUDE E P LATZKE 1 30.S/25.W/16 NW/SE

LADD PET JOHNSON 1-17 30.S/25.W/17 NW/SW

LADD PET WIDMER 1-17 30.S/25.W/17 660FN/1980FE/NE

LADD PET JOHNSON 2-17 30.S/25.W/17 330FN/660FW

LADD PET WIDMER 2-17 30.S/25.W/17 1980FN/990FE

LADD PET JOHNSON 3-17 30.S/25.W/17 330FN/1980FW

LADD PET CHURCH 1-18 30.S/25.W/18 S2/SE

TXO PROD CHURCH /A/ 1 30.S/25.W/18 660FE/1980FS

TXO PROD CHURCH 2 30.S/25.W/18 660FE/660FN

BANKS LEE OIL CANNON 1 30.S/25.W/19 NE/NE

PENDLETON LAND & EXPL WIDMER 1 30.S/25.W/19 660FN/990FW

PENDLETON LAND & EXPL ROBINSON 1 30.S/25.W/20
1540FN/1320FE

SUTTON O A GIBBONS 1 30.S/25.W/24 NW/NE

SUTTON O A LEWIS 1 30.S/25.W/27 NW/SE

SUTTON O A FERGUSON 1 30.S/25.W/27 SW/SW

SPINES EXPL NICKELSON 1 30.S/25.W/27 SW/SW

CIMARRON PET LEWIS CPC 98 30.S/25.W/27 E2/NE/NE

LADD PET NICKELSON 1-27 30.S/25.W/27 1980FS/4290FE

CIMARRON LEWIS 1 30.S/25.W/27 W2/NE/NE

RINE EXPL LEWIS 1-28 30.S/25.W/28 660FN/660FE

BROOKS HALL OIL CO BEESON 1 30.S/25.W/31 NW/SE

PENDLETON LAND & EXPL HATFIELD 1 30.S/26.W/1
1320FN/1180FW

OMG O&G PETRO 1 30.S/26.W/2 C SE

PENDLETON LAND & EXPL WRIGHT 1 30.S/26.W/14
660FN/110FW/NE

BANKS LEE CHANCE 1 30.S/26.W/15 C NW SW

BANKS OIL CO CHANCE 2 30.S/26.W/15 NW NW SW

PENDLETON LAND & EXPL RYAN POWELL 1 30.S/26.W/22
660FS/940FE

BANKS LEE OIL RATZLAFF 1 30.S/26.W/24 C SE NE

PENDLETON LAND & EXPL RATZLAFF 1-24 30.S/26.W/24
660FN/1880FW

PENDLETON LAND & EXPL JACKSON 1 30.S/26.W/24
1980FS/1320FE

PENDLETON LAND & EXPL PENKA 1 30.S/26.W/26 660FS/990FE

LADD PET POST 1 30.S/26.W/27 1980FN/1980FE

LADD PET POST 2-27 30.S/26.W/27 660FN/660FE

BURK ROYALTY HILDEBRAND 1 30.S/26.W/34 SW/NW/SE

MURFIN PLYMALE 1-35 30.S/26.W/35 660FS/1980FE

BURK PLYMALE 1-35 30.S/26.W/35 C SW SE

APPENDIX C

List of Wells in Regional Cross-sections and Used as Data Points for Maps Showing Updip Limits of "Gray group" Sequences.

Cross sections used in this investigation are contained within Kansas Geological Survey Open File.

Cross section A-A′

Anadarko Pet. Milhon 1-A 33s/32w/9 SW NE

Jones & Pickrell Neumann-Wheatly 1 33s/30w/19 NE NE

Cities Service Meyer E-2 33s/30w/20 SW NE NE

Agate Pet. Keystone 1-5 33s/29w/5 NW SE

Texas O & G Loeden 2 33s/27w/2 950fsl 1320 fwl

Hawkins O & G Roberts 1-9 33s/26w/9 W/2 NW

Tenneco Oil Co. Pyle 1-7 33s/25w/7 W/2 W/2 SW

Exxon Cox 1 33s/24w/4 NW SE SW

Petroleum Inc. Pike 1-3 33s/23w/3 800fwl 2250fnl

Mitchell Energy Gibson 4 33s/22w/9 SW SE NW

Quintana Pet. Co. Edmonston 1-3 33s/21w/3 1970fwl 2630 fsl

Cross section B-B′

Texas O & G Manke 1 29s/20w/6 NW NW SE

Samuel Gary Oil Trager 1-13 29s/22w/1 SW SW

Voyager Pet. Flangel 1 29s/23w/14

Texas O & G McConnell b-1 30s/24w/6 NE NE NE

Ladd Pet. Wear 1-8 30s/25w/8 SW NW

Ladd Pet. Barlett 1-13 29s/26w/13 SW SW SW

Ladd Pet. Nelson 1 29s/27w/14 NE NE SE

Continental Oil Meade 1 29s/28w/3 NE NE SW

Ladd Pet. Reed 1 29s/30w/3 330fnl 2310fwl

Texas O & G Waldron 1 29s/31w/26 SE SE

Pan American Pet. Rohmeyer 1 29s/32w/30 NE NW

Cross section C-C'

Northern Pump Co. Reeves 1 25s/33w/14 SE SE SE

Amoco Prod. Brookover 1 25s/32w/10 400fnl 400fel

Continental Energy Skaggs 1 25s/31w/34 NW NE NW

Hadson Pet. Mooney 1-15 25s/30w/15 SW SE

Hadson Pet. Hufford 1-8 25s/29w/8 NE NE

Patrick Pet. Snowbarger 1 25s/28w/6 NW NW

Rine Drlg. Salem 1 25s/27w/22 SE NW

Rine Drlg. Buehne 1 25s/26w/35 NW NW

Kingwood Oil Cain 1 25s/25w/18 SE NW

Cross section D-D'

Koch Expl. Clifton 1 21s/26w/13 SE NE

Helmrick & Payne Schlegel 1 21s/27w/21 1820 fnl 2215 fel

Goff Chennell 1 21s/28w/22 SW SW

Helmrich & Payne Schnieder 1 21s/29w/21

Ladd Pet. Rissler 1-a 21s/30w/32 NW NW NE

Anadarko Prod. Joyce b-1 21s/31w/16 SW NE

Cities Service Hullman 1-a 21s/32w/4 NE NW

Brown Co. Maume 10 21s/33w/31 NE NE

Brown Co. Fleagle 1 21s/34w/24 NE SE

Cross section E-E′

Anadarko Pet. Milhon 1-A 33s/32w/9 SW NE

Anadarko Pet. Boles 1-b 32s/33w/7 SW NE

Amoco Prod. Stapleton 3 31s/33w/1 NW SE

Pan American Pet. Rohmeyer 1 29s/32w/30 NE NW

Falcon Seaboard Drlg Meairs 1 28s/32w/18 SE NW

Bogert Oil Tee 1-20 27s/32w/20 E/2 E/2 SE

Pan American Pet. Kisner 1 26s/33w/36 NW SE

Shell Oil Stone 2-17 26s/33w/17 NW NW

Northern Pump Co. Reeves 1 25s/33w/14 SE SE SE

Continental Energy Smith 1 24s/32w/19 SW SE

Gear Pet. Walker 1-17 23s/32w/17 NW SE

Contineteal Energy Anderson 1 22s/33w/3 NW NE

Brown Co. Wampler 1 21s/33w/17 NW SW

Cross section F-F′

Ladd Pet. Rissler 1-a 21s/30w/32 NW NW NE

Woolsey Pet. Haag 1 23s/30w/6 NW SW NE

Scott Richie Busch 1 24s/29w/5 SE NW

Hadson Pet. Hufford 1-8 25s/29w/8 NE NE

Anadarko Prod. Humble 1-c 27s/31w/9 NE NW

Beardmore Drlg. Yeager 1 28s/30w/20 NE NE

Ladd Pet. Reed 1 29s/30w/3 330fnl 2310fwl

Hixon Development Borth 24-12 31s/30w/12 660 fsl 3315 fel

Cities Service Meyer E-2 33s/30w/20 SW NE NE

Cross section G-G′

Helmrich & Payne Schlegel 1 21s/27w/21 1820fnl 2215 fel

Falcon Expl. Berger 1 22s/27w/26 NW NW

Cities Service Salmans 1-a 26s/27w/9 2310fel 1650 fsl

Cities Service Shwartz 1 26s/27w/26 NE NE SW

Rine Drlg. Culver 1 27s/27w/9 SW SE

Pendleton Ld & Ex Asher 1 28s/27w/31 SW SW SW

Ladd Pet. Nelson 1 29s/27w/14 NE NE SE

Price Expl. Copenhagen 1 30s/27w/34 SE

Petroleum Inc. Chance 1-c 31s/27w/14 SW NW

Shamrock Oil Reimer 1 32s/27w/34 SW

Texas O & G Loeden 2 33s/27w/2 950fsl 1320 fwl

Cross section H-H'

Rine Drlg. Salem 1 25s/27w/22 SE NW

Irex Co. Frack 1 26s/29w/36 NW NW SW

Pendleton Ld & Ex. Pendleton 1 27s/29w/16 SW SW NE

Mobil Oil Koehn 1 28s/29w/24 SW NW

Rine Drlg. Salem 1 25s/27w/22 SE NW

Midco Schmidt 1 30s/31w/26 NE NE SE

Arco Dee 1 31s/31w/14 2000 fnl 330 fel

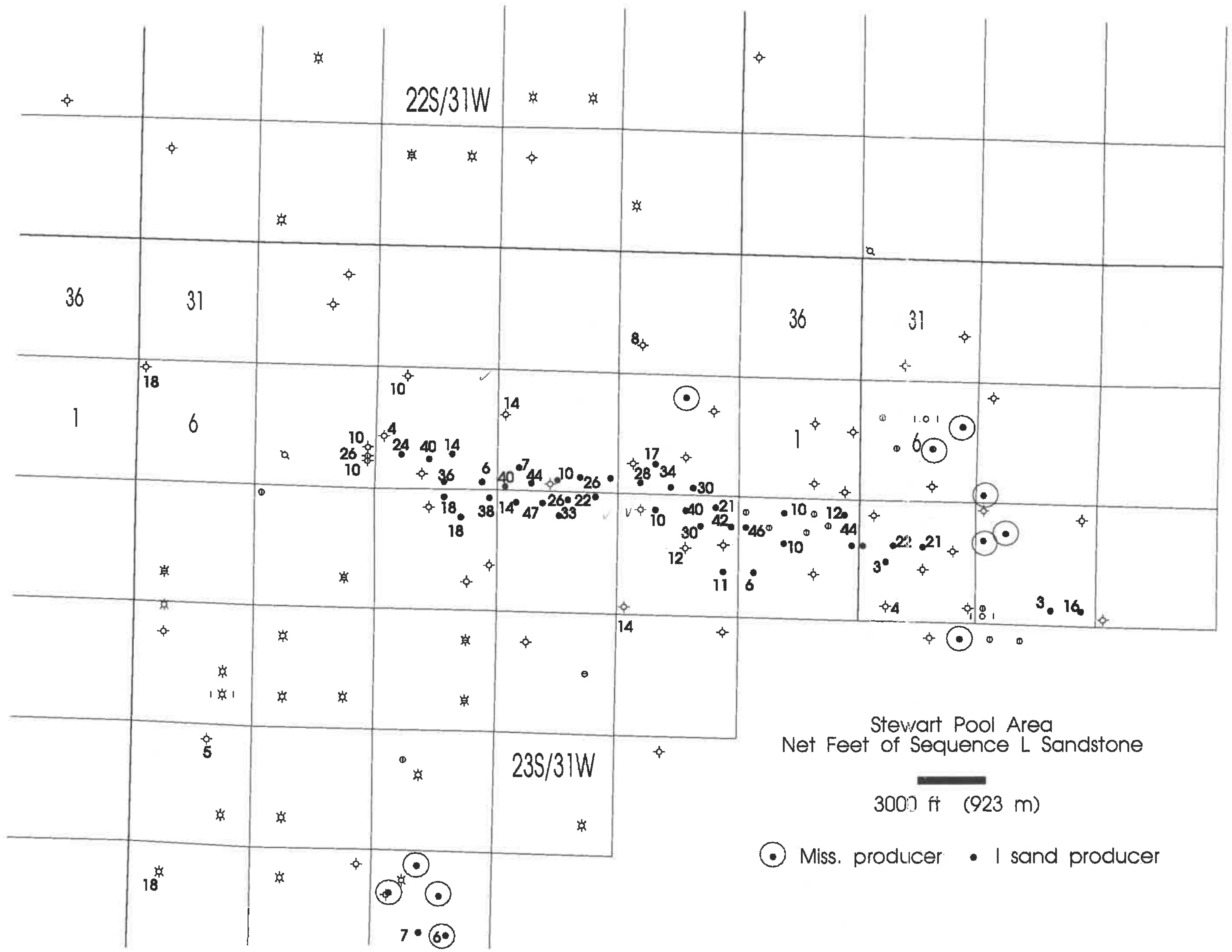
Kelloil Inc. Hunt 1 31s/31w/20 1320 fsl 660 fwl

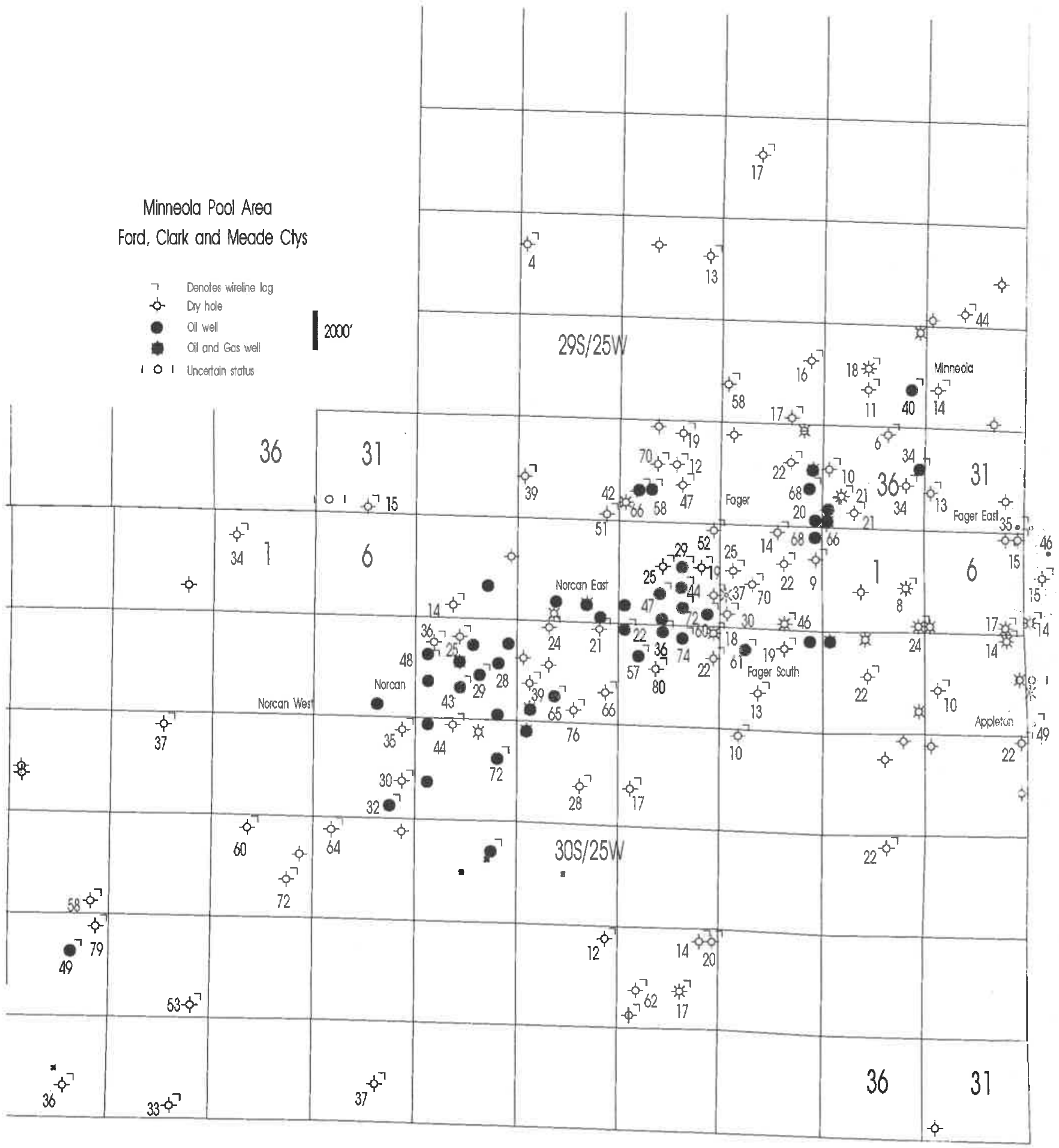
Tucker Prod. Hawk 1 32s/31w/26 NW NW

Anadarko Pet. Milhon 1-A 33s/32w/9 SW NE

APPENDIX D

Sequence I Sandstone
Thickness Data

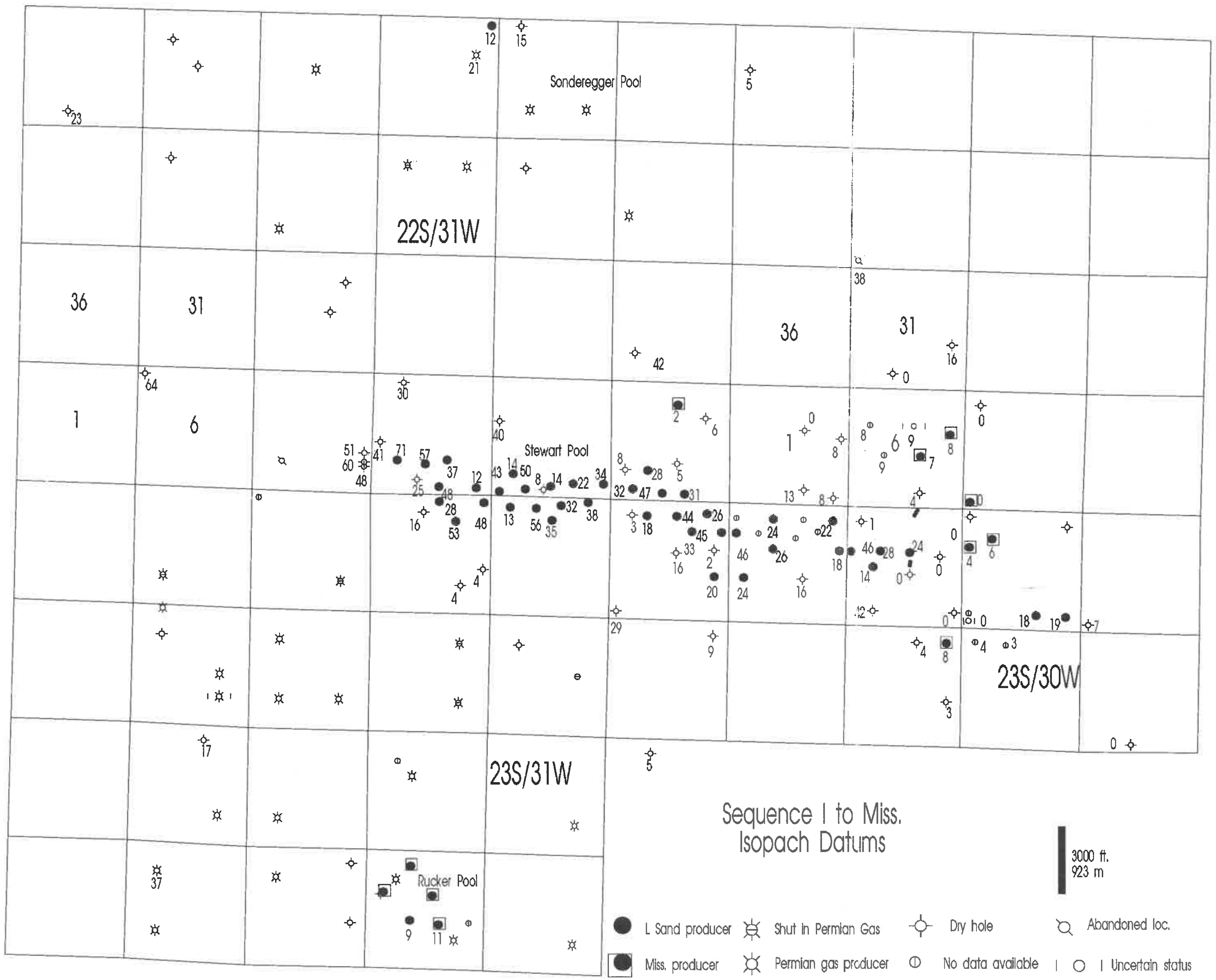




APPENDIX F

Base Seq. i to Miss. Isopach

Data



APPENDIX E

Sequence L isopach data in Stewart Pool area.

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