DEPOSITIONAL ENVIRONMENTS AND DIAGENESIS OF THE TONKAWA FORMAT (VIRGILIAN) IN WOODS AND PART OF WOODWARD COUNTIES, OKLAHOMA

By

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CHAPTER I

ABSTRACT

The study area is located on the northern shelf of the Anadarko Basin. It comprises some 1420 square miles of Woods and part of Woodward Counties, Oklahoma. The Tonkawa format represents the earliest regressive-transgressive couplet of the Douglas Group in the Virgilian Series. It is bounded above and below by the Haskell and Avant Limestones, respectively. Tonkawa sandstones are widespread over much of northern and northeastern Oklahoma and extend into eastern Kansas, where surface exposures are present.

In the study area, the sandstones have been divided into four stratigraphic "packages", each representing different episodes of deposition. A package consists of one or more sand bodies that are laterally equivalent.

The interval thins dramatically to the north and northwest as it approaches the carbonate shelf area. Isopach thicknesses vary from about 160 feet adjacent to the carbonate shelf to greater than 420 feet in the south and southeast parts of the study area.

The Tonkawa sandstones probably represent a high-constructive lobate delta system. A net sandstone isolith map of the format suggests a northeast source area. The

thinning of the interval probably represents the northern edge of the system in this area. Deltaic facies represented by the cores studied include prodelta, delta front, distributary-mouth bar, interdistributary bay, crevasse splay, and distributary channel.

Structure maps of the top of the limestones show a basinward dip to the south and southwest ranging from 28 to 37 feet per mile. A series of north-northeast trending anticlinal and synclinal structures are present on both limestones. These tend to be broad and gentle. No faulting was identified.

The dominant trapping mechanism in the Tonkawa sandstones is stratigraphic pinching out of sandstone bodies in an updip direction. Most of these sands probably represent distributary-mouth bar deposits.

The sands present in the cores are identified as subrounded, fine to very fine grained, sublitharenites. Metamorphic and sedimentary clasts make up the rock fragment component. Muscovite is the most abundant detrital constituent in the sands. Porosity ranges from 0 to 14% and is almost wholly secondary. Authigenic calcite and siderite constitute the major pore filling constituents. Authigenic chlorite, kaolinite, and illite clays are present, but only in minor amounts.

CHAPTER II

INTRODUCTION

Location

This thesis is a regional subsurface study of the Tonkawa format (Virgilian) on the north shelf of the Anadarko Basin in northwestern Oklahoma. The area of investigation encompasses approximately 1420 square miles in Woods and the northeastern part of Woodward Counties (T24N-29N and R13W-19W) (Figure 1).

Objectives

The objectives of this study include:

1. Recognition of the distribution, trends, and geometry of the Tonkawa sandstones.
2. Determination of possible depositional environment(s) of the various sandstones.
3. Determination of past and present structure in the study area.
4. Recognition of the local hydrocarbon trapping mechanisms.
5. Evaluation of the petrology, diagenesis, and porosity types in the Tonkawa sands.

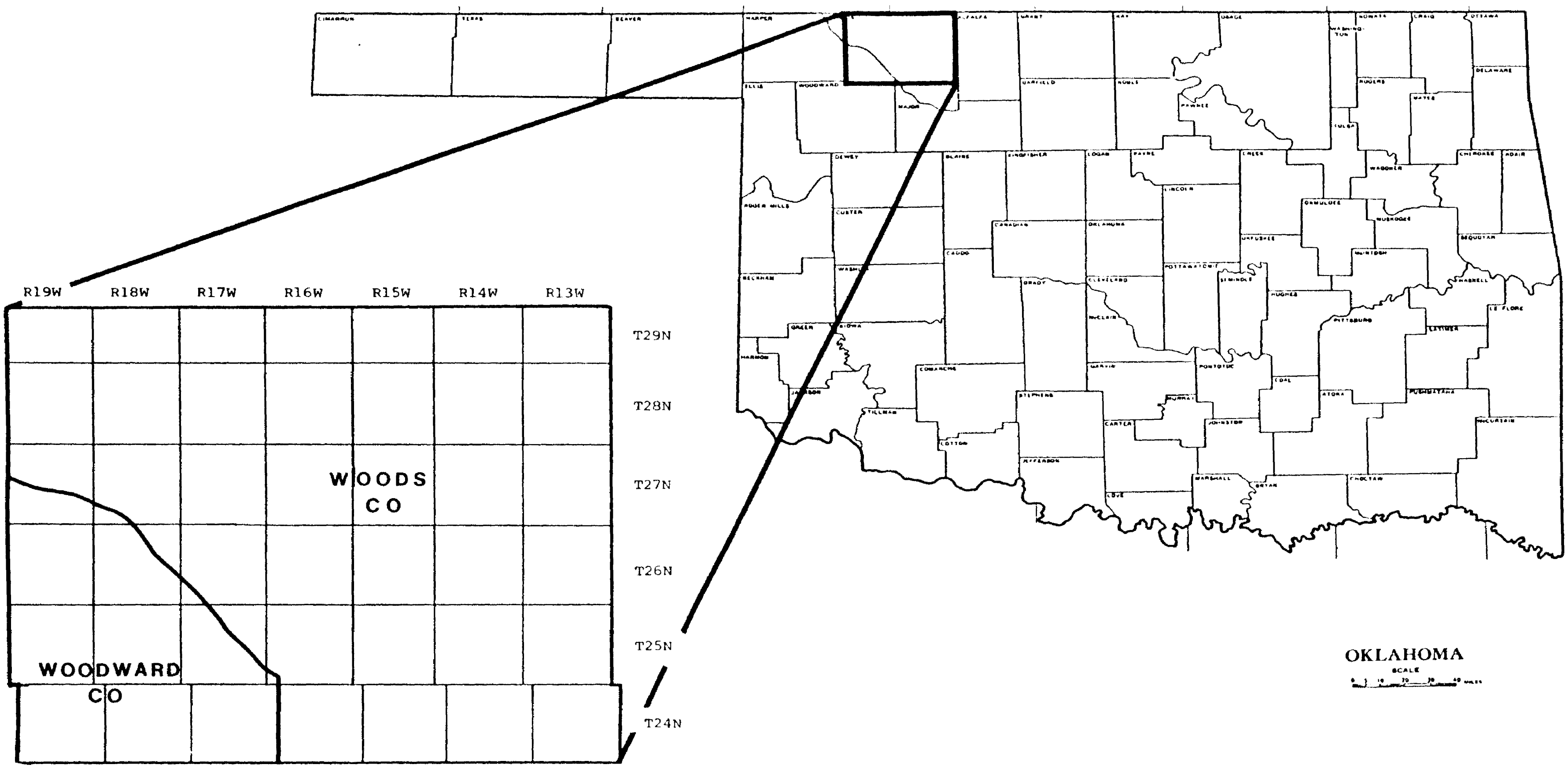


Figure 1. Location Map of Study Area.

Methodology

Subsurface data were obtained utilizing various electric logs from 1058 wells. The tops of the limestone marker beds were measured by using resistivity-sp and resistivity-gamma ray wire line logs. The construction of two structure contour maps and a total interval isopach map involved the use of these data (Plates I, II, III). Individual resistivity-sp logs were used in the construction of 8 cross sections (Plates VI, VII, VIII) and in the construction of two electric log signature maps of the Tonkawa (Plates V and VIII).

Sandstone intervals were delineated using gamma ray logs in conjunction with resistivity and various porosity logs. These sands were assumed to be reservoir quality. In other words, the porosity was developed enough to permit economic production, if hydrocarbons were present in the sands. A minimum porosity of 7 to 8% (Stewart, 1987, person. comm.) is required for most of the sands in the Anadarko Basin region to be economic. The following method was used to meet this criterion:

1) The highest and lowest readings of the gamma ray curve for each well were measured. These numbers represent the shale baseline and a clean limestone or sandstone, respectively. The difference between the high and low readings was then divided in half.
2) A line was drawn on the log at the point corresponding to the number derived in step 1.

> This line is designated as the 50% shale content line and corresponds to between 7-8% porosity as calculated from various porosity logs. In reality, there is usually much less shale than this in the sands, but the heavy mineral constituents and clays will tend to pull the gamma ray curve towards the shale baseline (Al-Shaieb, 1987, person. comm.).

Data gathered from this work were utilized in the construction of a net sandstone isolith map of the interval.

The net sandstone isolith map was originally constructed using values of the sp-curve to determine sandstone bed thicknesses. The values measured by this method were, on the whole, greater and very inconsistent compared to the thicknesses derived from the other log types and from the cores. The map drawn with these data showed erratic sand trends, indicating a southeast source area instead of a east to northeast source area as is judged to be correct from maps drawn using gamma ray and porosity log types. Another problem inherent in the use of the sp-curve was that many of the curves were poorly developed or not developed at all. This probably was due to small potential differences between the drilling fluid and formation water rather than low porosities in the sands or high formation pressures. A reason for this could be the presence of evaporites in the overlying Permian rocks. Salty waters from these units mix with the drilling fluid, making the fluid saline.

Four cores of the Tonkawa interval were studied in detail. Two of the cores were from locations within the study area, two others from areas adjacent to and west of the study area. Each core was calibrated to the appropriate resistivity-sp/gamma ray electric log in order to understand the log signature response to lithologies in the cores, and to assist in the interpretation of depositional environments. These cores were logged to determine variations in grain size, thicknesses of various lithologic units, and to describe any sedimentary structures present.

Thirty-seven thin sections were prepared from samples selected from the four cores and examined using the petrographic microscope. Five hundred points were taken on each of the thin sections to determine petrology, grain size, and porosity types. These data were used to compile a diagenetic history of the Tonkawa sandstones. X-ray diffraction analysis was run on 20 of these samples to aid in the identification of constituents. In addition, x-ray diffractions of natural, glycolated, and heated samples of clay extractions for 6 of the 20 samples were run in an effort to identify accurately authigenic and diagenetic clays present in the sections.

Various oil and gas field maps (Oklahoma Oil Maps, Inc, 1983) were used in the construction of the field and Tonkawa production map for the study area. Information regarding Tonkawa production was taken from scout tickets and production reports.

Previous Works

Tonkawa sandstones have been written about in many publications, even though few workers have actually performed studies specifically on them. Most work that has been conducted involved workers in Kansas, where outcrops of the sandstones can be found.

In Kansas usage, the Tonkawa is known as the "Tonganoxie", or more commonly, the "Stalnaker" (Lukert, 1949). Originally, the "Tonganoxie" referred to outcrop exposures in eastern and northeastern Kansas. The name later became a subsurface name as well, when equivalent subsurface sands were identified (Merriam, 1963). The name "Stalnaker" is the name originally applied to the subsurface sands in south-central and southeast Kansas. Except for this section, the name "Tonkawa" has been used for all the sands in the interval, regardless of the geographic location. Figure 2 shows the areas that have been mapped or have had cores examined by the previous authors discussed below.

The "Tonganoxie" sandstone was first described in separate articles by Bennett, Hall, and Haworth in 1896 (Lins, 1950). In 1929, Bass presented the first subsurface study of the "Stalnaker" (Lins, 1950). Lukert (1949) published a paper in which he illustrated the stratigraphic relationships of Paleozoic rocks in central Kansas and north central Oklahoma with a series of cross sections. In this report there is a description explaining the correlations of

Authors

1. Lins (1950)
2. Sanders (1959)
3. Griffith (1981)
4. Winchell (1957)
5. Walton & Griffith (1983)
6. Khaiwka (1968)
7. Pate (1959)
8. Kumar & Slatt (1984)
9. Fies (1988), this study

Cores Used in this Study:

A
B
C
D

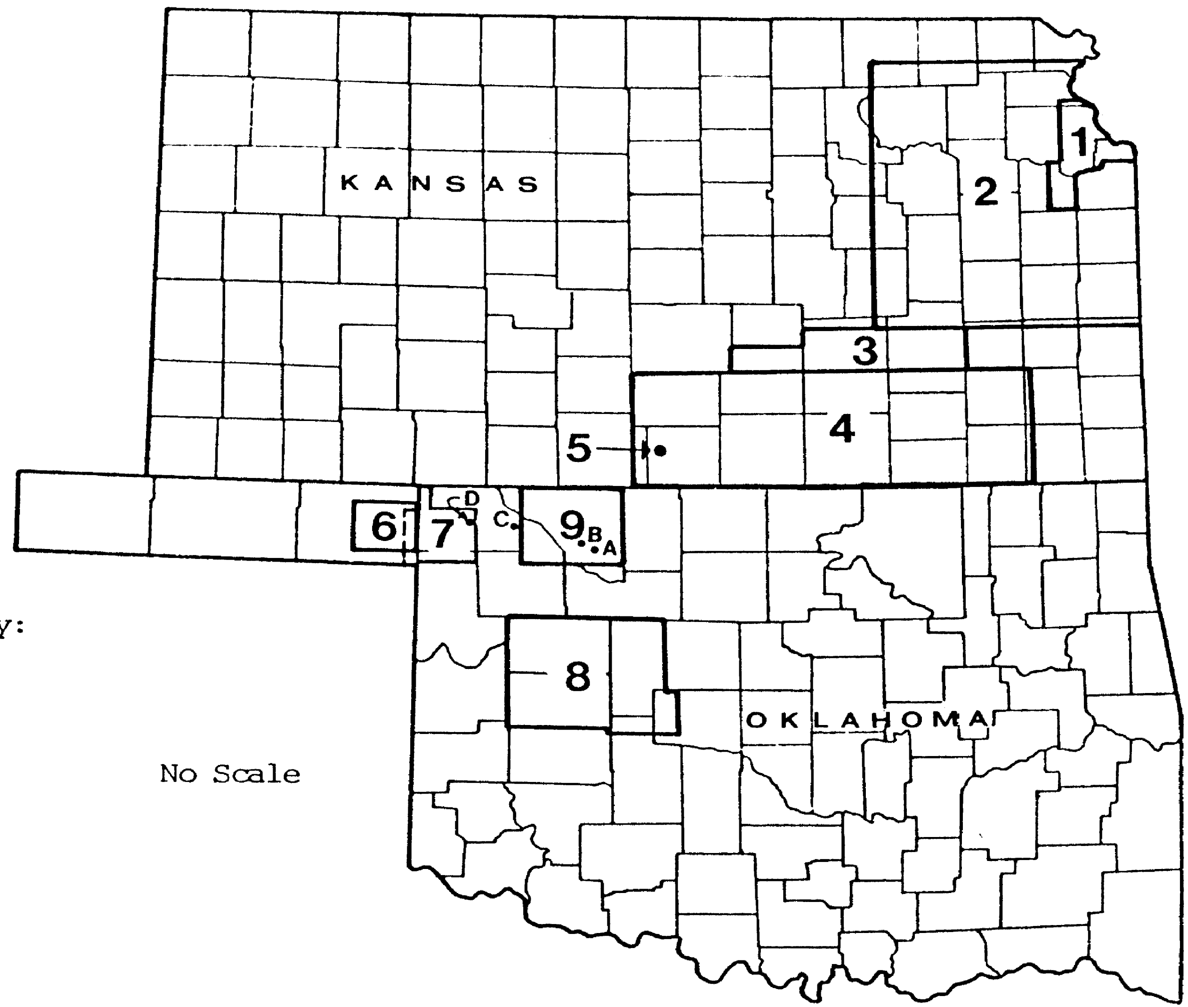


Figure 2. Locations of Previously Mapped Areas and Locations of Cores Studied (Kansas section modified after Griffith, 1981).

the Tonkawa ("Stalnaker") to overlying and underlying units.

Lins (1950) was the first to map the subsurface distribution of sands. He proposed a fluvial depositional environment for the "Tonganoxie" in northeastern Kansas.

In 1957, Winchell mapped the distribution of the "Stalnaker" in south-central Kansas. Using this map and several cross sections across the study area, he concluded that the "Tonganoxie" of northeastern Kansas was equivalent to the "Stalnaker" of south-central Kansas.

Sanders (1959) mapped and described the "Tonganoxie" in the subsurface of northeastern Kansas in his study of the sandstones in the Douglas and Pedee Groups.

Ball (1964) studied the Douglas Group in the eastern Mid-continent extensively and concluded that the "Tonganoxie" and "Stalnaker" were equivalent, substantiating Winchell's stratigraphic interpretation. He used exposures, subsurface data, and cross sections in Kansas, Nebraska, Missouri, and Oklahoma to verify his conclusions.

In 1981, Griffith mapped the "Tonganoxie" in eastern Kansas, filling in the gap between the areas mapped by Lins and Winchell. With this work, the distribution of the Tonkawa ("Tonganoxie") throughout most of Kansas became known.

The first work on the Tonkawa in Oklahoma was done by Pate (1959). He studied the Tonkawa sandstones in the Laverne-Mocane field, Harper County. A map produced in this study shows the general facies of the Tonkawa interval over the northwestern Oklahoma shelf area. However, most attention was paid to the sands in the Laverne field district. There, he mapped the structure and distribution of the sands, and provided cross sections illustrating the stratigraphic relationship with the adjacent Lansing Group.

In 1963, he produced additional maps in which he broke down three sand members present in the area. Trapping mechanisms in the field were explained as well.

Khaiwka (1968) was the first to provide a deltaic model to the Tonkawa sands with his work in Beaver County. Lane (1978) disagreed, interpreting a marine slope sand associated with a tidal pass for much of the same area. It should be noted that Lane did not actually study the Tonkawa sandstones. Instead, he focused on the limestones of the Lansing Group. His conclusions are based primarily on the morphology of the limestones.

Kumar and Slatt (1984) published a report on the Tonkawa sandstones in the Anadarko Basin in western Oklahoma. The focus of their work was to interpret the depositional environment of the lowest sand unit in the interval.

Allen (1954), Powell (1954), Gallaspy (1958), Gibbons (1960), Bowles (1959), Capps (1959), and Jordon, Pate, and Williamson (1959), are others who have written about the stratigraphic relationships of Tonkawa interval in the Mid-continent of Oklahoma. Most of these conclusions, however, were drawn by works of Lukert (1949), Winchell (1957) and

Pate (1959).

In their treatment of the paleogeography and depositional environments of the Tonkawa interval, Rascoe (1962), Busch (1974), and Rascoe and Adler (1983), base their interpretations mainly on the works of Pate (1959) and Khaiwka (1968).

CHAPTER III

STRATIGRAPHIC FRAMEWORK

Introduction

The Upper Pennsylvanian stratigraphy in the Mid-continent is divided into the Missourian and Virgilian Series, respectively (Figure 3). There was an overall transgression of shallow seas onto relatively stable shelf areas during each of these epochs. These transgressions were interrupted periodically by rather extensive regressions, which shifted the carbonate shelf edge southward, towards the basin (Kumar & Slatt, 1984). The development of large delta complexes during these regressions resulted in the deposition of copious amounts of sandstones and shales on the shelf and slope areas.

Correlations and age of the Tonkawa interval will be fully discussed following an explanation of a "format" and how it is used in this study.

Genetic Intervals

Bates & Jackson (1980) describe "format" (sensu Forgotson, 1957) as "an informal, laterally continuous lithostratigraphic unit that includes two or more lithologically dissimilar units but is suitable for regional

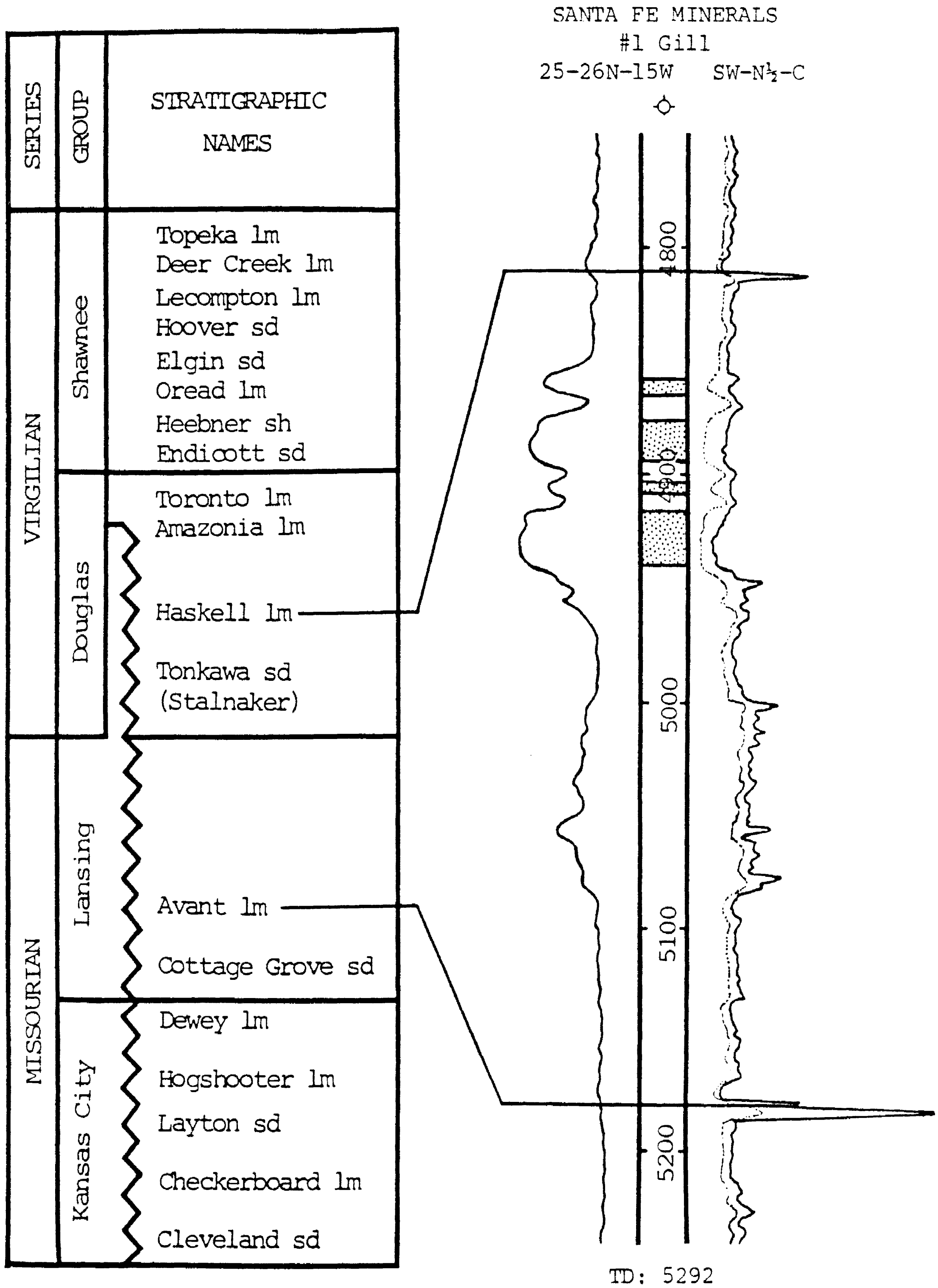


Figure 3. Upper Pennsylvanian Stratigraphic Column (modified from Chenoweth, 1979) and Tonkawa Format Type Log.

mapping... The term is applied to an operational unit representing strata sandwiched between observable markers that are believed to be isochronous surfaces."

This term was expanded on by Busch (1971) in describing the genetically related lithologic components of deltas and was later developed in more detail in 1974. His term, "Genetic Increment of Strata (GIS)", is defined as "an interval of strata deposited during one cycle of sedimentation in which a lithologic component is genetically related to all the others. It is essential that the upper boundary be a lithologic-time marker. The lower boundary may be a lithologic-time marker, an unconformity, or a facies change from marine to nonmarine (Busch & Link, 1985). Figure 4 gives examples of each of these conditions.

An isopach map of a GIS shows the basinward direction by the increasing thickness of the interval. Local thickening or anomalous "terracing" taking place parallel to the contours can indicate differential compaction between sandstone and shale, thus outlining position and trends of the sandstones (Busch & Link, 1985).

Correlations and Discussion

Introduction

The Tonkawa format represents the lowest regressive-transgressive couplet in the Douglas Group of the Virgilian Series (Figure 3). This interval corresponds to profile B in Figure 44, and is the only profile described by Busch

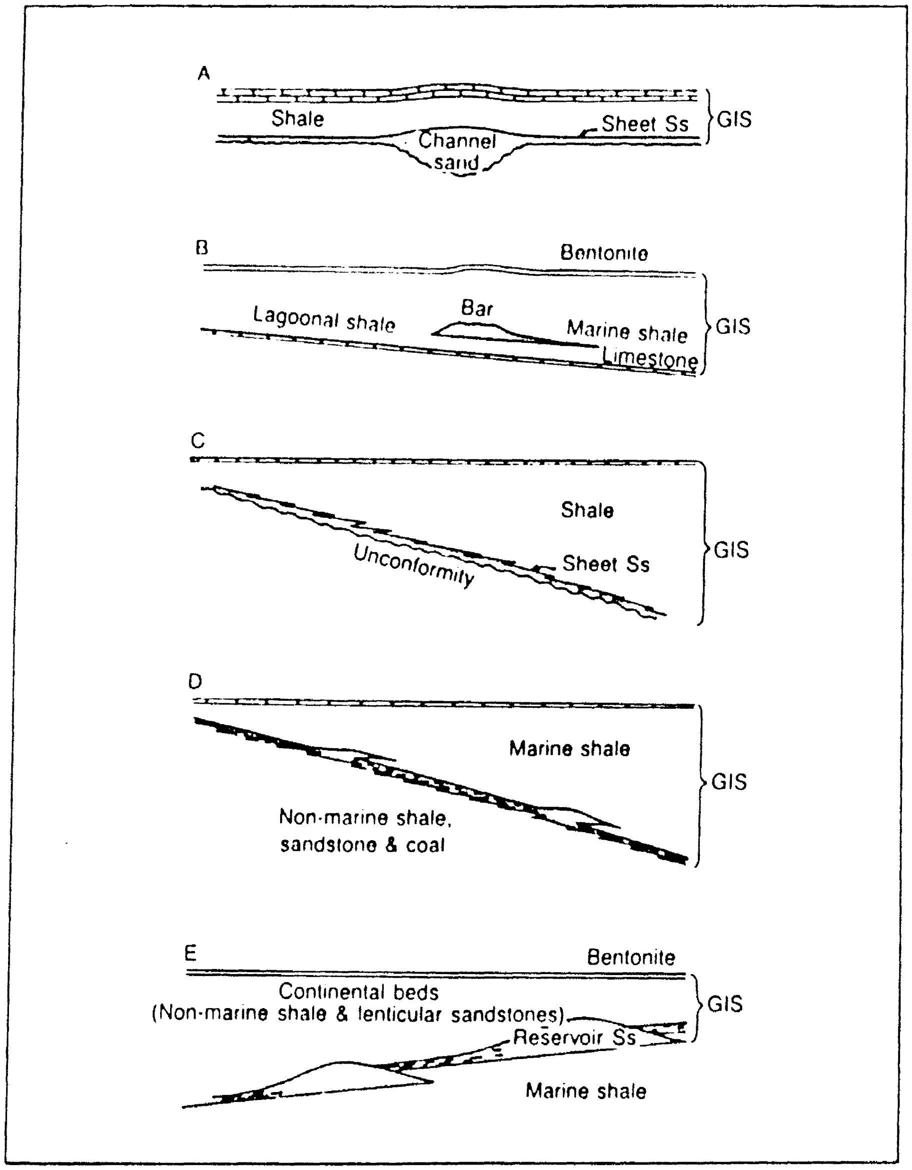


Figure 4. Diagrammatic illustrations of Genetic Increments of Strata (GIS) (modified from Busch, 1985).

which illustrates the Forgotson concept of a "format". The upper boundary is drawn at the top of Haskell Limestone and the base lies at the top of the underlying Avant Limestone (Figure 3). These limestones are persistent regionally and serve as good marker beds.

Total isopach thicknesses in the study area range from less than 160 feet near the carbonate bank to greater than 420 feet (Plate 3). Thicknesses gradually increase in the direction of the Anadarko Basin (Kumar & Slatt, 1984).

A series of five stratigraphic electric log cross sections was prepared in order to illustrate the Tonkawa format interval and to delineate sandstones within the interval (Plates I & II). Locations of these sections are shown on Figure 5. The reader is referred to the cross sections when reading the following sections of this chapter.

Dating the Tonkawa Format

The age of the Tonkawa format interval has been the subject of considerable debate. The two schools of thought are: (1) the Tonkawa is Virgilian age and constitutes the lowermost part of the Douglas Group (Lukert, 1949; Winchell, 1957; Ball, 1964; Lane, 1978); (2) the Tonkawa is Missourian and is the equivalent to the upper part of the Lansing Group (Pate, 1959; Gibbons, 1958; Capps, 1959).

In this report, the Tonkawa is considered to be Virgilian for the following reasons:

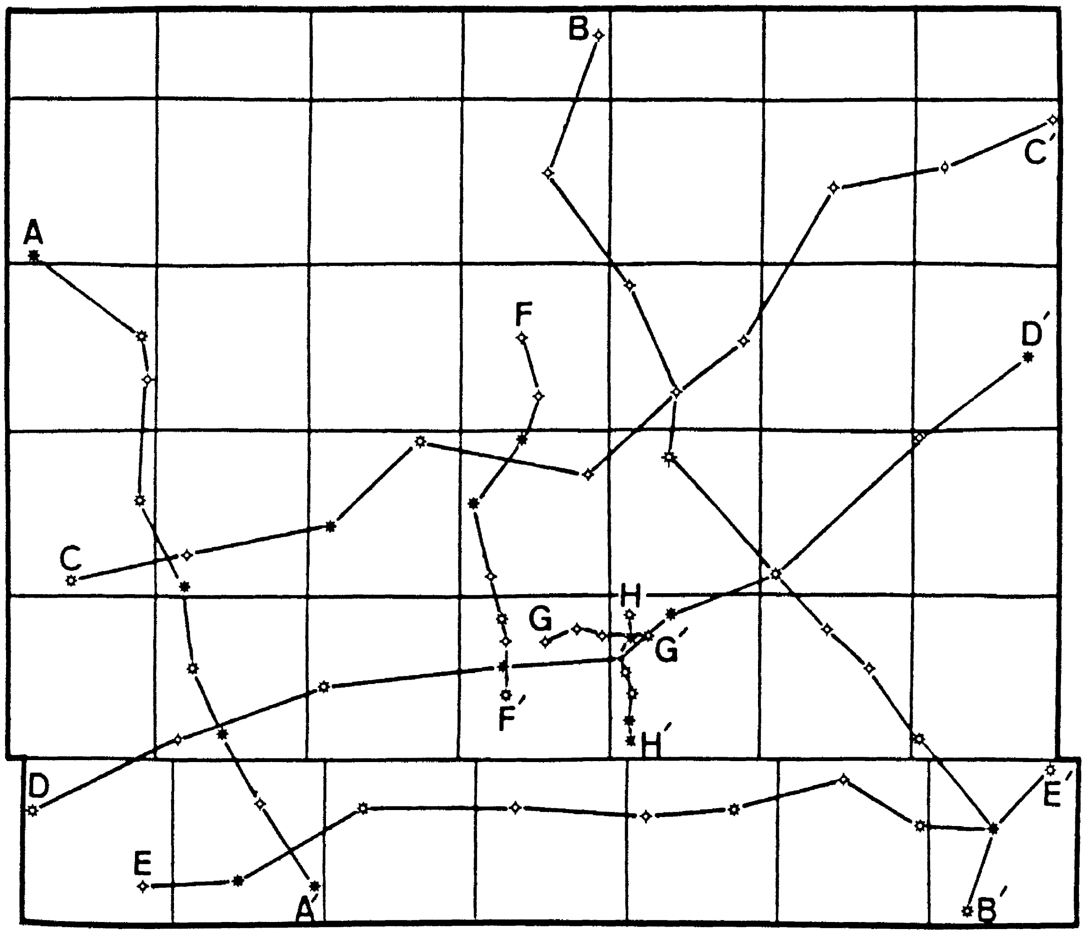


Figure 5. Locations of Cross Sections.

(1) The Haskell Limestone overlying the Tonkawa in Kansas has been dated as Virgilian (Ball, 1964).

(2) The Tonkawa sandstone is present in surface exposures in Kansas. These outcrops show the sands sitting unconformably on top of Lansing Group limestones, however, the contact is apparently not erosional (Ball, 1964).

(4) The surface exposures have been traced into the subsurface in south central Kansas (Winchell, 1957) and into northern Oklahoma (Lukert, 1949; Ball, 1964).

(5) The distribution of the sands mapped in this study coincides with those mapped in Kansas (see Chapter VI, Figure 21).

The relationship of the Tonkawa format to the adjacent limestones on the shelf areas in northwestern Oklahoma is not understood at this time. Cross sections A-A' and B-B' (Plate I) show the change from clastic facies to carbonate facies. Wells 2 and 3 on cross section A-A' illustrate that this change takes place over 1.6 miles. Extensive studies are needed to completely resolve the question of age and stratigraphic relations of these units.

Avant Limestone

The Avant Limestone is thought to be, "in part equivalent to the Raytown" Limestone member of the Iola Formation in Kansas (Moore, 1949). It is included as part of the Kansas City Group in Kansas, however, in the Anadarko region of Oklahoma, the Avant is considered to be part of the Lansing Group (Chenoweth, 1979). The Avant ("Raytown") is the uppermost of three members and is underlain by the Muncie Creek shale and Paola limestone members, respectively. This formation is very widespread, and extends from Iowa into central Oklahoma (Davidson, 1978).

The Avant is very thin in some areas of Kansas and Oklahoma, and is absent in others. Thicknesses are known range "from a featheredge" in southern Kansas (Moore, 1949) to about 53 feet in southern Osage County, Oklahoma (Davidson, 1978).

In the study area, the Avant varies from about 2 feet to near 9 feet in thickness and averages about 5 feet (Figure 3). It is directly overlain by a 2-4 foot thick "hot" shale that shows a characteristic gamma ray signature on electric logs.

Moore (1949) describes the Raytown (Avant) as a light-buff to creamy-white colored, fossiliferous limestone that is generally "overlain by thin algal and crinoidal limestone or by alternating beds of more or less flaggy limestone and shale." In his study of an outcrop of the Avant Limestone in north-central Oklahoma, Davidson (1978) described the 44 feet thick interval as being massive, mottled blue-gray to steel-gray, finely to coarsely crystalline, algal, skeletal calcilutite and calcarenite. By using staining techniques, he was also able to identify dolomite and ferroan calcite in the rock.

Haskell Limestone

The Haskell limestone has been considered to be a marker bed in northwestern Oklahoma by Jordan (1957). Actually, it is used as a marker bed throughout northern Oklahoma, as well as in the southeastern and central part of Kansas (Moore, 1949).

Miller and Swineford (1957) described the Haskell in Kansas as being a calcilutite. The Earlsboro, Curtis-Stark No. 1 core (20-T25N-R15W), utilized in this study, contains the Haskell Limestone Member. It is a 2-foot thick unit of brown algal boundstone that is very sandy near the base. A complete description is given in Chapter VII.

In the study area, the Haskell is locally very silty and sometimes absent (Plate II). In these areas, the limestone was either never deposited or was deposited and eroded. Thicknesses range from 0 to about 4 feet and average around 2 feet (Figure 3).

Tonkawa Sandstones

The sandstones of the Tonkawa format are widespread and continuous over most of the northern shelf areas of Oklahoma. These trend in an east to northeast direction and have been traced into eastern and northeastern Kansas, where surface exposures can be found (Lukert, 1949; Winchell, 1957; Walton & Griffith, 1983). The sands are calcareous, micaceous, very fine- to medium-grained, and porous.

The sandstones in this study were divided into four separate "packages", rather than distinguishing each sand body individually. Each package is a unit of interbedded sandstone and shale, distinguished from over or underlying packages by shale units. The boundaries were determined by the top and base of the uppermost and lowermost sand unit in each group.

The depths of these packages vary according to their location in the study area. Generally, the groups occupy a higher stratigraphic position northward towards the carbonate shelf area. The packages are always positioned consistently to one another in any given location. In other word, Package "B" will always overlie package "A", and so on.

Package "A" ranges from about 140 feet to 290 feet below the Haskell limestone. The ranges for packages "B", "C", and "D" are 70 to 165 feet, 35 to 157 feet, and from just below the Haskell limestone to 55 feet, respectively. Figures 6 and 7 show the stratigraphic positioning of these packages. Cross sections A-A' thru E-E' (Plates I & II) illustrate the relationships of the individual sand beds to each other.

Packages "B" and "C" are the most widespread groups in the study area. Package "D" has the least amount of sand, but is seen sporadically throughout the area. The lowest group, package "A", is present only in the south-central and

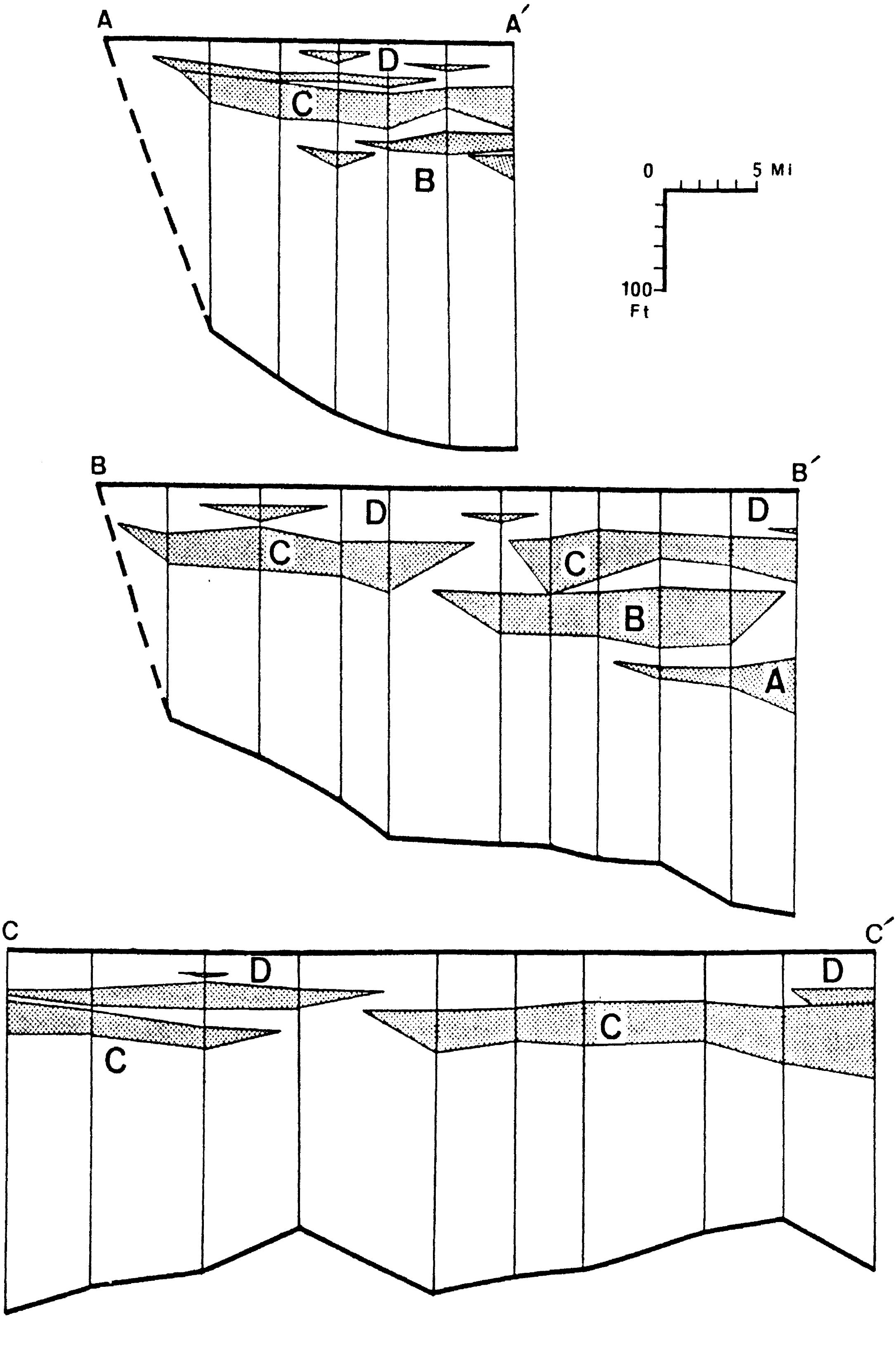


Figure 6. Distribution and Thickness of Tonkawa Sandstone Packages in Cross Sections A-A', B-B', and C-C'.

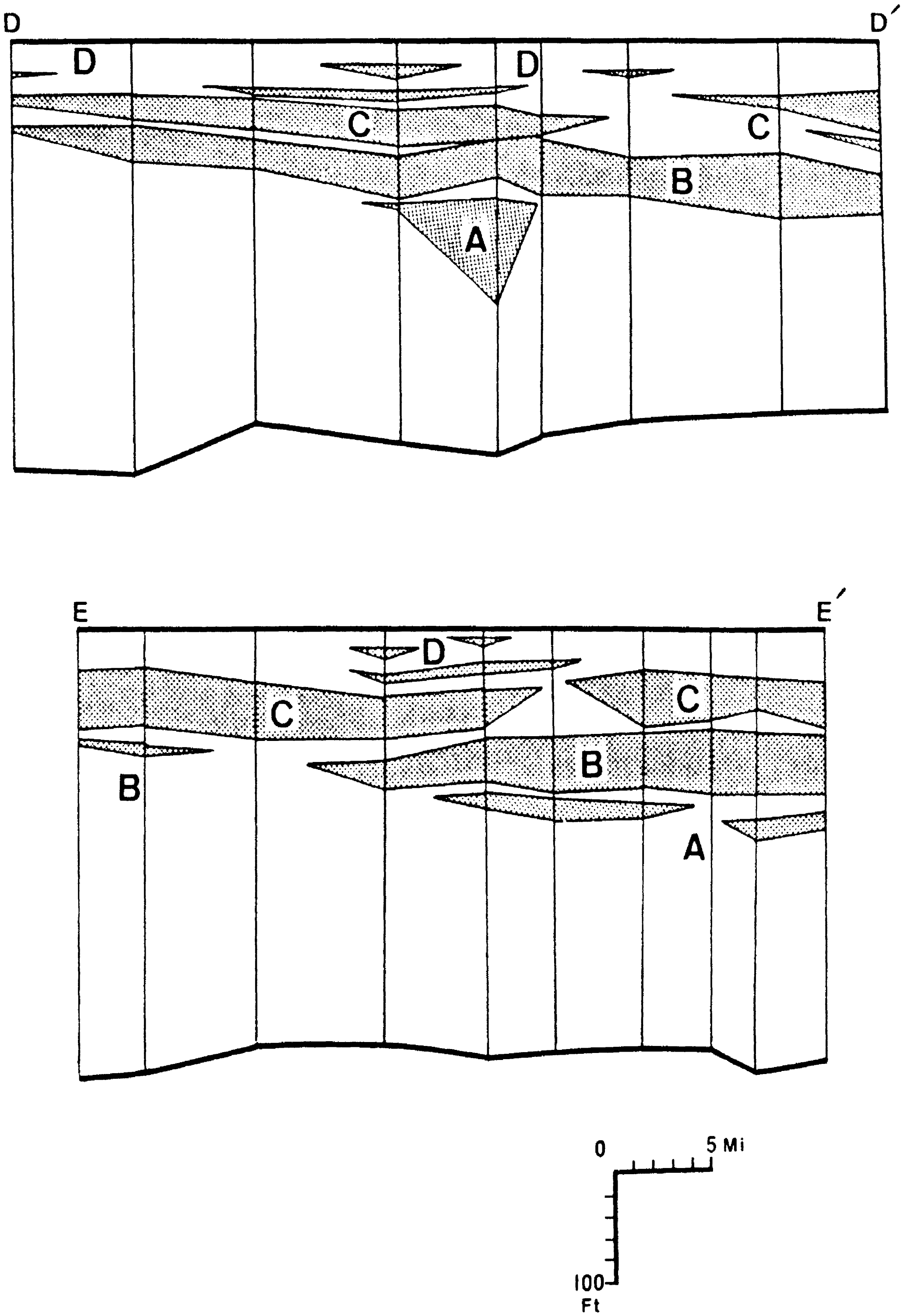


Figure 7. Distribution and Thickness of Tonkawa Sandstone Packages in Cross Sections D-D' and E-E'.

southeastern part of the study area.

Each of the packages, except "D", has an overall coarsening upward trend indicating increased sandstone/ shale ratios. This probably represents deltaic progradation into a basin with time. Lobe switching in a deltaic environment could be responsible for such sequences as seen in these groups.

CHAPTER IV

STRUCTURAL FRAMEWORK

Regional Setting

The Anadarko Basin is a northwest trending, asymmetric basin that occupies most of western Oklahoma (Figure 8). It is bounded to the east by the Nemaha Ridge and to the south and southwest by the Amarillo-Wichita Mountains. On the north and northwest, the basin is bordered by a large, relatively stable shelf area which dips gently into the basin itself (Figure 9).

The following explanation of the prominent structural features is derived from Barrett (1963) and Rascoe and Adler, (1983). East of the Anadarko Basin, in northeastern Oklahoma and western Arkansas is the Ozark Mountain Uplift (Figure 8). Late in the Desmoinesian Epoch, this area had become a relatively high mountain range and was the source area for many of the sediments being brought into the basin.

By Virgilian time, this range was reduced to a topographically low-lying landmass. Sediment brought into the Anadarko from this uplift diminished. At the same time, the Cratonic area north of Oklahoma was beginning to supply abundant sediments to the basin, making it the major source area of this epoch.

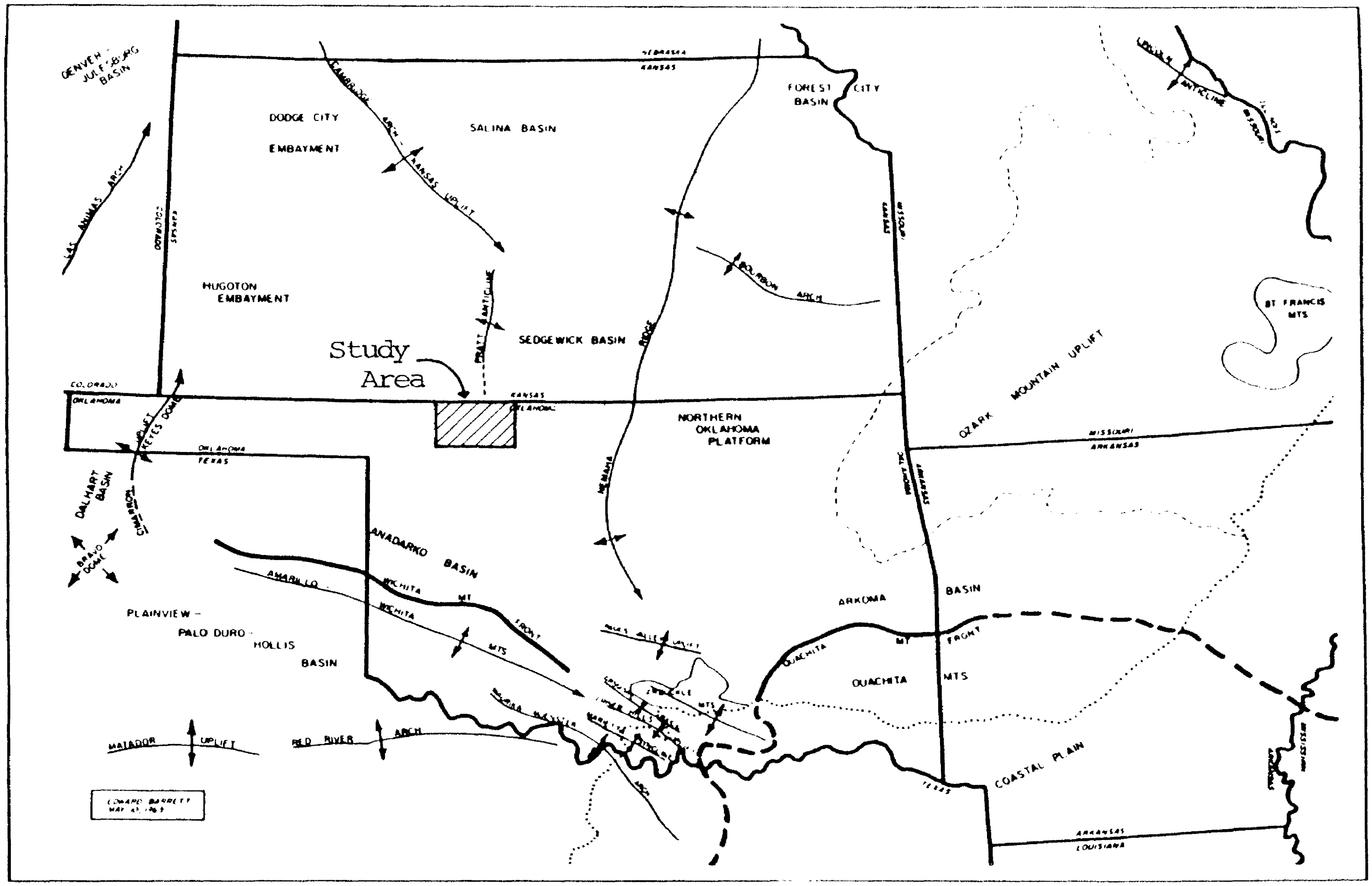


Figure 8. Tectonic Features of the Mid-Continent (modified from Barrett, 1963).

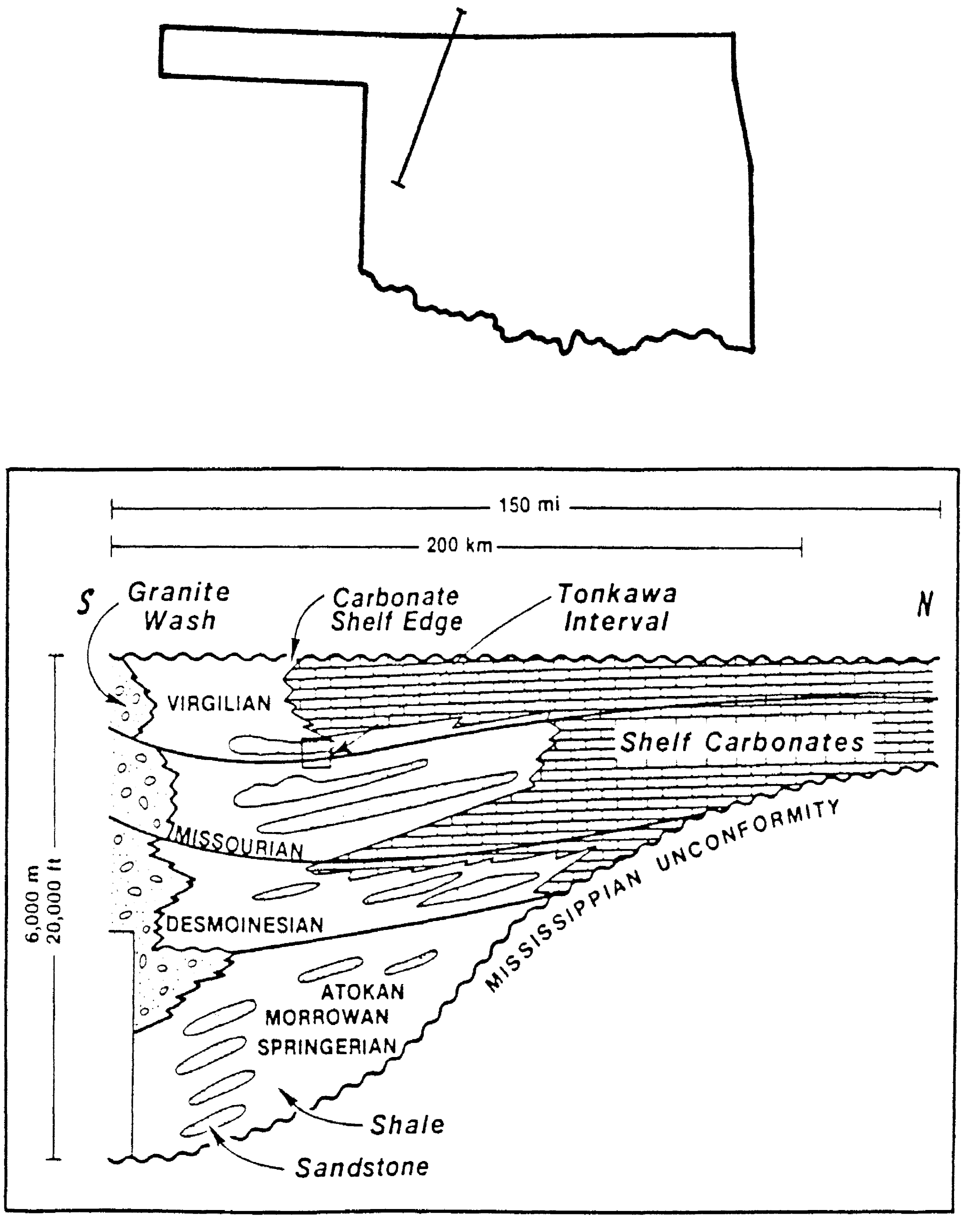


Figure 9. General Cross Section Showing Pennsylvanian Stratigraphy in the Anadarko Basin (modified from Kumar & Slatt, 1984).

The Ouachita Mountain Range in southeast Oklahoma was the primary source area for terrigenous clastics of the Anadarko Basin during the Missourian Epoch. This mountain range was much higher than the Ozark Mountains, hence the greater clastic input to the basin. By the early to middle Virgilian, it too was eroded to a much lower, hilly area. Sediment from this area was still being deposited, but to a much lesser degree than before.

The Wichita Mountain Uplift, meanwhile, supplied sediment to the southern part of the basin. This mountain area was the major source area for this part of the basin from the Middle Pennsylvanian to the beginning of the Permian Period.

Local Structure

Avant Limestone

The structure contour map on the top of the Avant limestone shows a predominantly east-west strike with a southerly dip of approximately 37 feet per mile (Plate I). This strike shifts to a more northwest-southeast direction in some local areas. The corresponding southwesterly dip maintains about the same gradient.

The Avant has a series of broad, north-northeast trending anticlines and synclines. In addition, this limestone shows a much more discrete north-west trending series of highs and lows. These structural features are only secondary trapping mechanisms for hydrocarbons.

Haskell Limestone

The structure on top of the Haskell Limestone was mapped over a large part of the north shelf area by Gibbons (1960) (Figure 10). Another structure map on top of the Haskell Limestone in southeastern Kansas was made by Winchell (1957) (not shown).

Both of these maps show a general southwesterly dip which gradually changes into a more southerly dip as it moves further west onto the shelf area. Gibbons' map shows a dip of approximately 33 feet per mile on the shelf area, increasing to about 53 feet per mile in the basin. A more detailed structure contour map of the study area prepared by the author (Plate II) indicates a southerly dip of approximately 28 feet per mile, which is consistent with that mapped by Gibbons.

As with the Avant limestone, the Haskell map shows a series of gentle north-south trending anticlines and synclines. Some of the anomalous highs and lows may be explained as a result of differential compaction of the underlying silts and clays with respect to sands upon burial.

Neither of the limestones mapped show any evidence of faulting. Any faults probably are local features with little displacement.

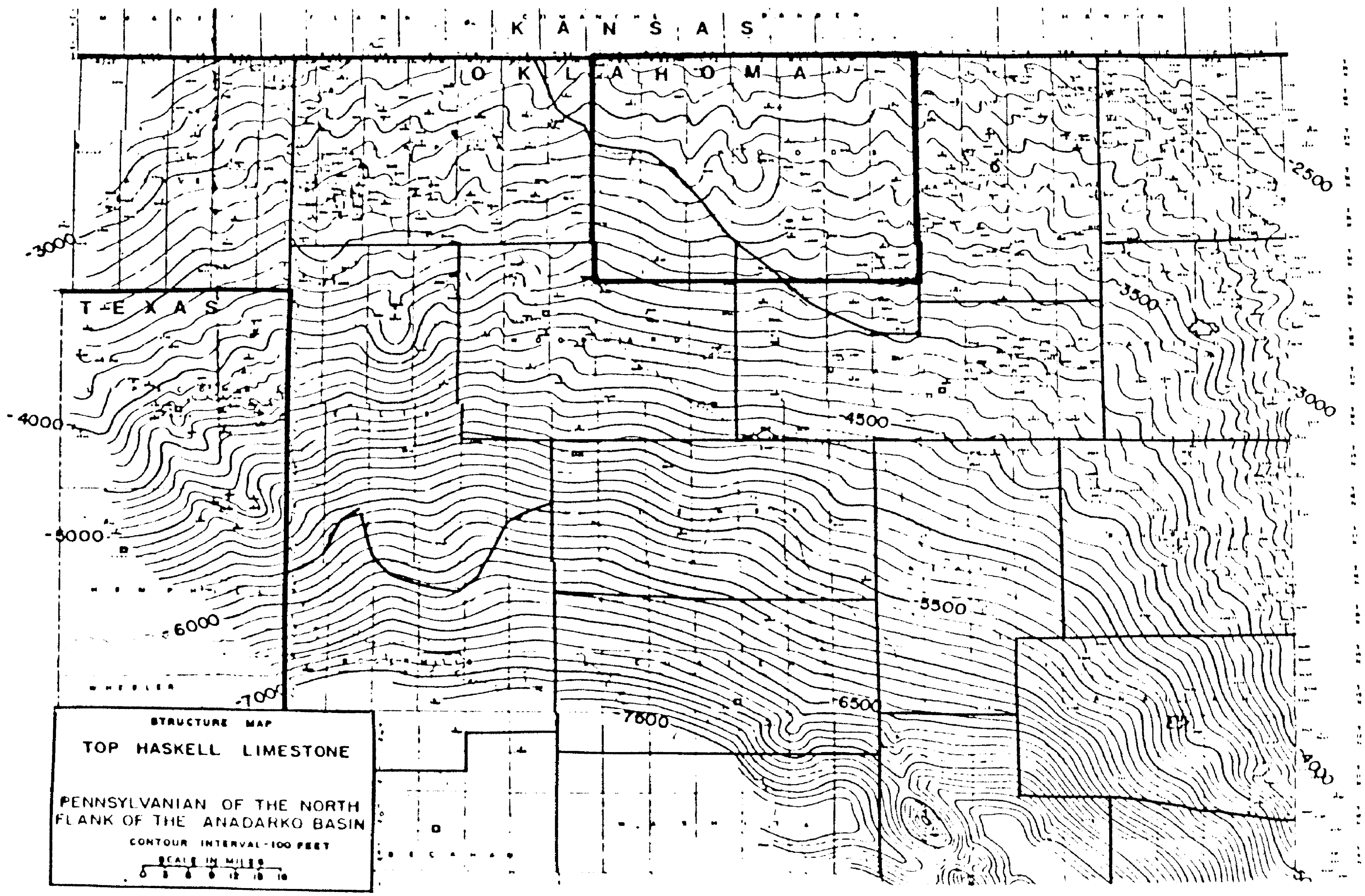


Figure 10. Structure Map on Top of Haskell Limestone on the Northern Shelf of the Anadarko Basin (from Gibbons, 1969). Study Area is Outlined.

CHAPTER V

DEPOSITIONAL FRAMEWORK

Introduction

The depositional environments of the Tonkawa format have previously been poorly understood. This is due mainly to the lack of concentrated study on the interval. In addition, most of the work that was done was not thorough. Electric log studies and subsurface mapping were performed without benefit of data from core or outcrops and vice versa. This resulted in interpretations that tended to be quite varied.

The various depositional systems proposed by those who have worked on the Tonkawa generally fall into two broad categories: coastal plain and marine clastic depositional systems. The coastal plain systems discussed by previous workers can be subdivided into: fluvial systems (Lins, 1950; Sanders, 1959; Griffith, 1981) and deltaic systems (Khaiwka, 1968; Griffith, 1981; Walton & Griffith, 1983), whereas the marine systems are divided into: open marine sheet sands or bars (Winchell, 1957; & Pate, 1959), slope sands associated with tidal passes (Lane, 1978), and submarine fans (Kumar & Slatt, 1984).

The first interpretations were done on the Tonkawa in eastern Kansas. Lins (1950) noted that this sand unit in northeastern Kansas may have been deposited by low-gradient fluvial channels. Sanders (1959) agreed with Lins, adding that southward of the area described by Lins was probably a "distributary system developed by basinward drainage." A fluvial environment was also proposed by Griffith (1981) for the sands in central Kansas.

Khaiwka (1968), in his study of the Tonkawa sandstones in Beaver County, Oklahoma, was the first to suggest the possibility that the sands were deposited in a deltaic environment. This idea was substantiated by Walton and Griffith (1983), who described a Tonkawa interval core taken from a well in Harper County, Kansas (Figure 2) as being deltaic. They stated that the "structures and sequences... are remarkably similar to those described for the modern Mississippi Delta (Coleman & Prior, 1980)." They also proposed the likelihood of a deltaic system in south-central Kansas which was fed by fluvial channels to the north.

Paleogeography and paleoenvironments for the early Virgilian were illustrated by Moore (1979) (Figure 11). He described clastics as prograding from the northeast and east across the shelf areas of southern Kansas and northern Oklahoma.

Padgett (1988, personal comm.) is also interpreting a deltaic environment for the Tonkawa interval in Dewey County, Oklahoma. He is using core evidence in conjunction with various subsurface maps to support his claim. His

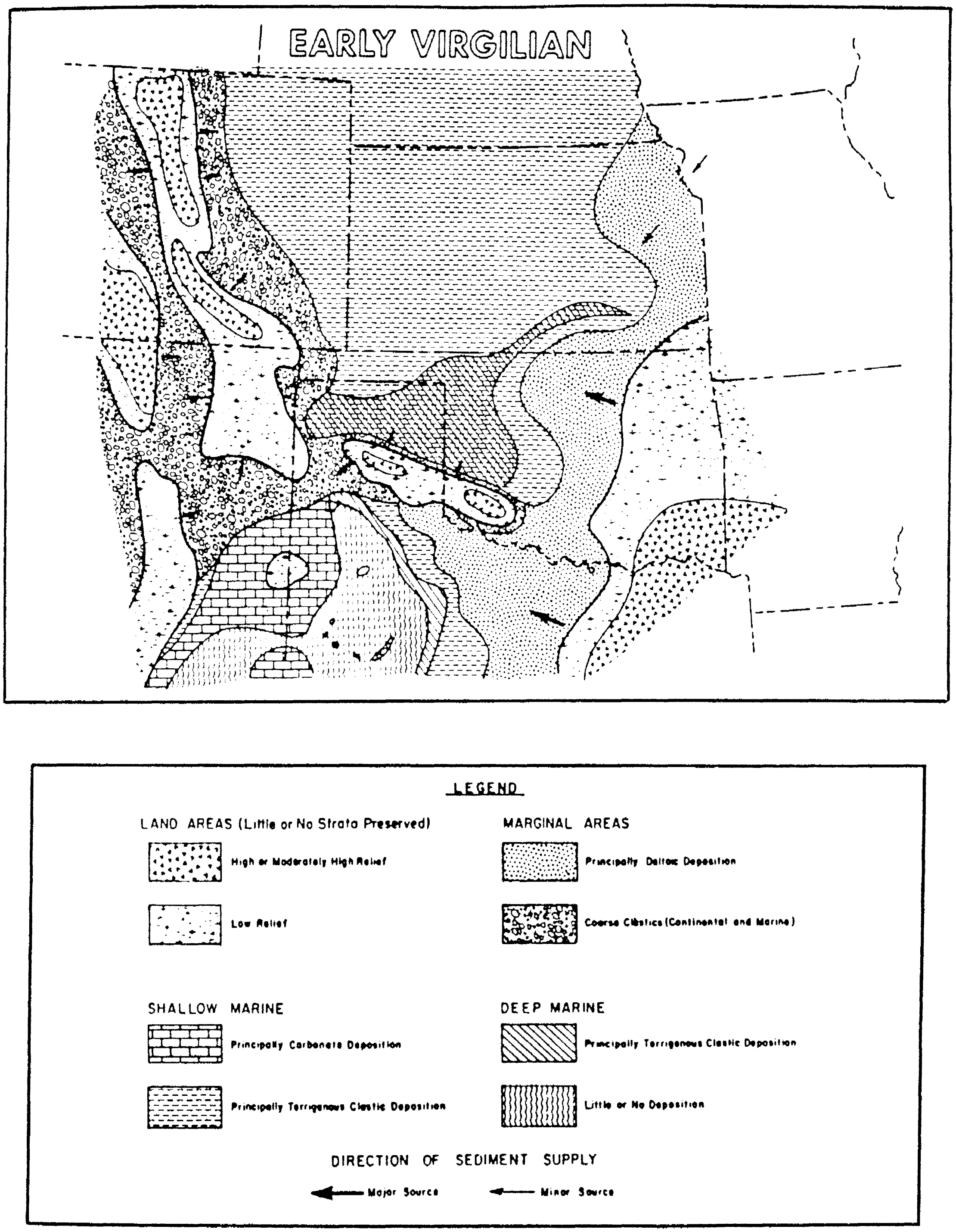


Figure 11. Generalized Paleogeography and Paleoenvironments of the Early Virgilian (from Moore, 1979).

study area occupies a portion of the area previously studied by Kumar and Slatt (1984).

The first paper describing the Tonkawa in the Sedgwick Basin in south-central Kansas was published by Bass in 1929 (Lins, 1950). He suggested that the sediments in the basin were deposited as a sheet sand in a marine environment. Winchell (1957) mentioned that sand occupying ancient channels in central Kansas were of marine origin and not fluvial. He also described a near shore marine environment for at least part of the sheet sand in south central Kansas. Pate (1959) described the Tonkawa sands in Harper County, Oklahoma (Figure 2) as being "bars" but did not explain a depositional environment. Bowles (1959) also suggested "off-shore bars" in his study of the subsurface geology of Woods County, presumably relying, at least in part, on data presented by Pate.

Lane (1978), using data presented by Pate (1959) and Khaiwka (1968), derived the theory of a marine slope sand that either migrated into or out of a tidal pass. Such an environment would be part of a barrier bar complex. His study area was in Beaver County, Oklahoma and encompassed much of the same area as Khaiwka's. Finally, Kumar and Slatt (1984) suggested a submarine-fan and slope facies for the Tonkawa sandstones in the Anadarko Basin. One core was utilized in their study.

Fluvial and deltaic terrigenous clastic systems are the most likely depositional environments of the Tonkawa format for several reasons. First, this interval represents a complete regressive-transgressive couplet, as described in Chapter IV. One would expect to have sediment deposited from terrigenous sources during such a regression.

Secondly, lines of evidence involving electric log signatures, subsurface maps, and cores described in later chapters of this report suggest that the sands in the study area reflect deposition in a deltaic environment.

Third, most of the Pennsylvanian sandstones in the Mid-continent region are recognized to have been deposited in deltaic, fan delta, and associated fluvial systems (Brown, 1979). There are many publications that supply evidence substantiating this claim. The reader is referred to "Pennsylvanian Sandstones of the Mid-Continent" published by the Tulsa Geological Society (1979) for more information pertaining to other Pennsylvanian sandstones.

Finally, several workers giving interpretations of fluvial and deltaic environments have core and outcrop data to use as evidence, whereas only Kumar and Slatt (1984) provide such data in their submarine fan interpretation.

Cratonic Delta Models and Facies

Introduction

High-constructive lobate and elongate delta models for the Mid-continent region have been described by Brown (1979). Both can be directly applied to some degree to the Tonkawa deltaic system present in the study area.

The following sections first describe deltaic facies of modern and ancient deltas based on the work of Coleman & Prior (1980, 1982) and Swanson (1980). These interpretations are then incorporated in the descriptions of the cratonic delta models. Also included are views expressed by Cleaves (1984) in his treatment of terrigenous depositional systems of Paleozoic rocks in the Mid-continent.

Deltaic Environments and Facies

Each principle deltaic environment is characterized by a suite of facies. The relationships of these facies to one another must be understood in order to properly interpret ancient stratigraphic sequences. Figure 12 shows the principle deltaic environments and illustrates facies relationships to each other and to sea level (Swanson, 1980).

Cores and associated log suites of the Tonkawa interval in the study area are interpreted to be bay-fill, distributary channel, and distributary-mouth bar facies of lower delta plain and subaqueous delta front deposits. These facies are discussed below.

Bay-fill deposits are those sediments that infill interdistributary bays in the lower delta plain. The sedimentation pattern for these deposits "is one of shallow, brackish water to marine clays encroached upon by a coarsening-upward sequence" (Busch & Link, 1985). Crevasse

(A)

SPECIFIC ENVIRONMENTS	GENERAL ENVIRONMENTS: DELTAIC PLAIN	DELTA FRONT	PRODELTA	OFFSHORE MARINE
NATURAL LEVEE	LAMINATED CLAY AND SILT MINOR SAND			
MARSH	ORGANIC RICH CLAY MINOR SILT			
BACKSWAMP	ORGANIC RICH CLAY MINOR SILT			
MEANDER LOOP CHANNEL	ORGANIC RICH CLAY AND SILT MINOR SAND			
POINT BAR	CROSSBEDDED SANDSTONE AND GRAVEL •			
LAKE	LAMINATED CLAY AND SILT			
TIDAL FLAT	LAMINATED CLAY SILT AND MINOR SAND			
BEACH	LAMINATED CLEAN SAND •			
DUNE	CROSSBEDDED CLEAN SAND •			
"STRAIGHT" DISTRIBUTARY CHANNEL	LAMINATED TO CROSSBEDDED SAND, SILT, AND CLAY •			
STREAM MOUTH BAR OR "FAN"		LAMINATED AND CROSSBEDDED GRAVEL, SAND, SILT, AND CLAY •		
BAY OR LAGOON		LAMINATED OR BURROWED CLAY MINOR SILT AND SAND		
SHOREFACE		LAMINATED AND BURROWED SAND, SILT, AND CLAY •		
CREVASSE		CROSSBEDDED SILT AND SAND •		
UNDIFFERENTIATED DELTA FRONT		LAMINATED AND CROSSBEDDED CLAY, SILT, AND SAND		
UNDIFFERENTIATED PRODELTA			LAMINATED CLAY AND THIN CLAYEY LIMESTONE	
TURBIDITE FLOW			LAMINATED SILTS, SANDS AND GRAVELS •	LAMINATED SILTS AND SANDS •
OFFSHORE MARINE				LAMINATED CLAY AND THIN CLAYEY LIMESTONE

(B)

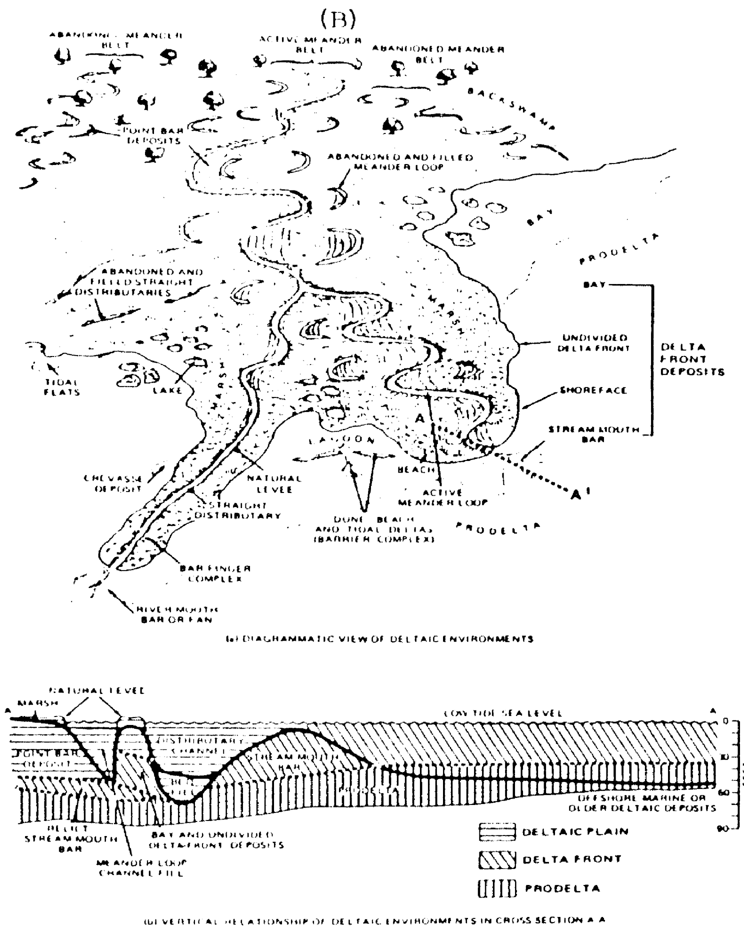


Figure 12. Deltaic Facies: (A) Classification of Deltaic Environmental Facies; (B) Principal Shallow-water Deltaic Environments and Facies with Their Relationship to One Another and to Sea Level. (both modified from Swanson, 1980).

splays extend seaward across shallow bays through systems of bifurcating channels. Eventually, these systems reach a maximum distance of progradation and then gradually become inactive. At this point, subsidence increases relative to deposition, allowing the system to be inundated by marine waters, thus completing the cycle (Coleman & Prior, 1982). Figure 13 is a summary diagram illustrating the major characteristics of bay-fill deposits.

Another deltaic facies present in the Tonkawa are distributary channels. Coleman and Prior (1980, 1982) have seen little evidence of abandoned distributary channels in modern deltas being infilled with sands, except where channels bifurcate or if substantial amounts of sand are available during initial stages of infilling. Swanson (1980) suggested that the abandoned distributary channels may have filled with sandstone "if the distributary had a thick bed load of sand and is abandoned relatively slowly."

Thick, sand-filled channels, however, are seen in the ancient rock record. Brown (1979) noted that individual channel sands are thin, but can become multistoried, or stacked, if there were several reactivations of the channel. Where these sands are closely associated with stream-mouth bar deposits, they will become part of the stream-mouth bar complex (Swanson, 1980). Sometimes isolated bodies of these sands occur on the delta plain. They usually have a narrow, elongate, and thin geometry and trend roughly perpendicular to the ancient shoreline (Swanson, 1980).

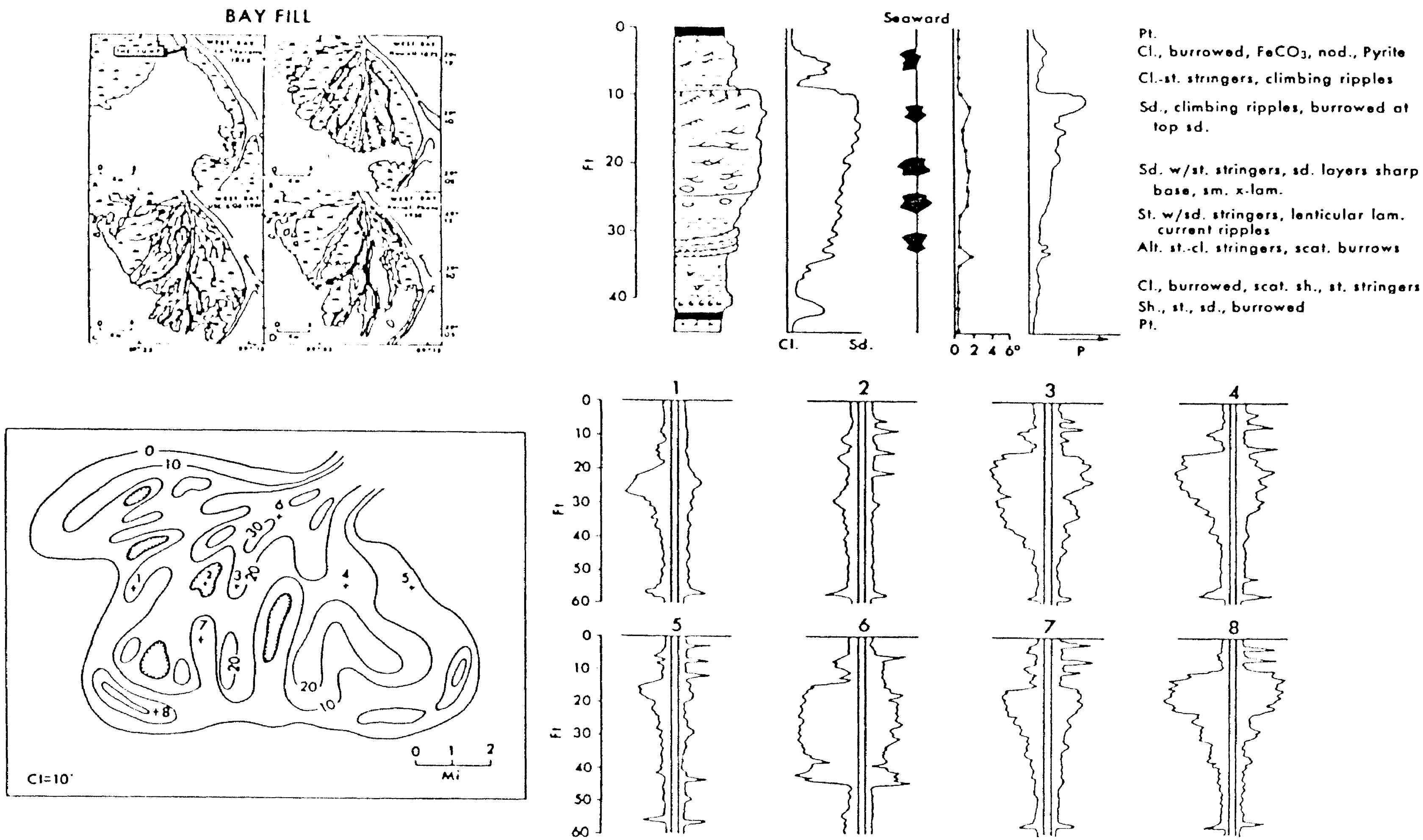


Figure 13. Summary Diagram Illustrating the Major Characteristics of Bay-Fill Deposits in the Lower Delta Plain (from Coleman & Prior, 1982).

Both modern and ancient distributary channel-fill deposits tend to have sharp bases and fine upwards, however, if abandonment was rapid, a sharp upper contact may develop. Figure 14 shows the distributary channel characteristics in modern deltas. Electric log #3 in the figure probably bests illustrates the log signature for a single abandonment episode in Pennsylvanian deltas. Figure 15 is a distributary channel model (Brown, 1979) of this facies in ancient cratonic deltas.

Distributary-mouth bars, also referred to as stream-mouth and channel-mouth bars, occur in that part of the delta where the highest rate of deposition occurs. Sediments in this facies are the coarsest deposited in the delta. Finer materials such as silts and clays may be deposited during periods of low river flow. Progradation causes these sands to be deposited over delta front silts and clays (distal bar facies) and results in a coarsening upwards sequence (Figure 16). The geometry of distributary-mouth bars is influenced by various effluent dynamics and marine processes.

High-Constructive Deltas

High-constructive deltas were first described by Fisher and McGowen (1967) as those deltas influenced most by fluvial-related processes. The associated (constructional) facies prograde basinward and form the bulk of total delta sediment volume (Cleaves, 1984). These facies are

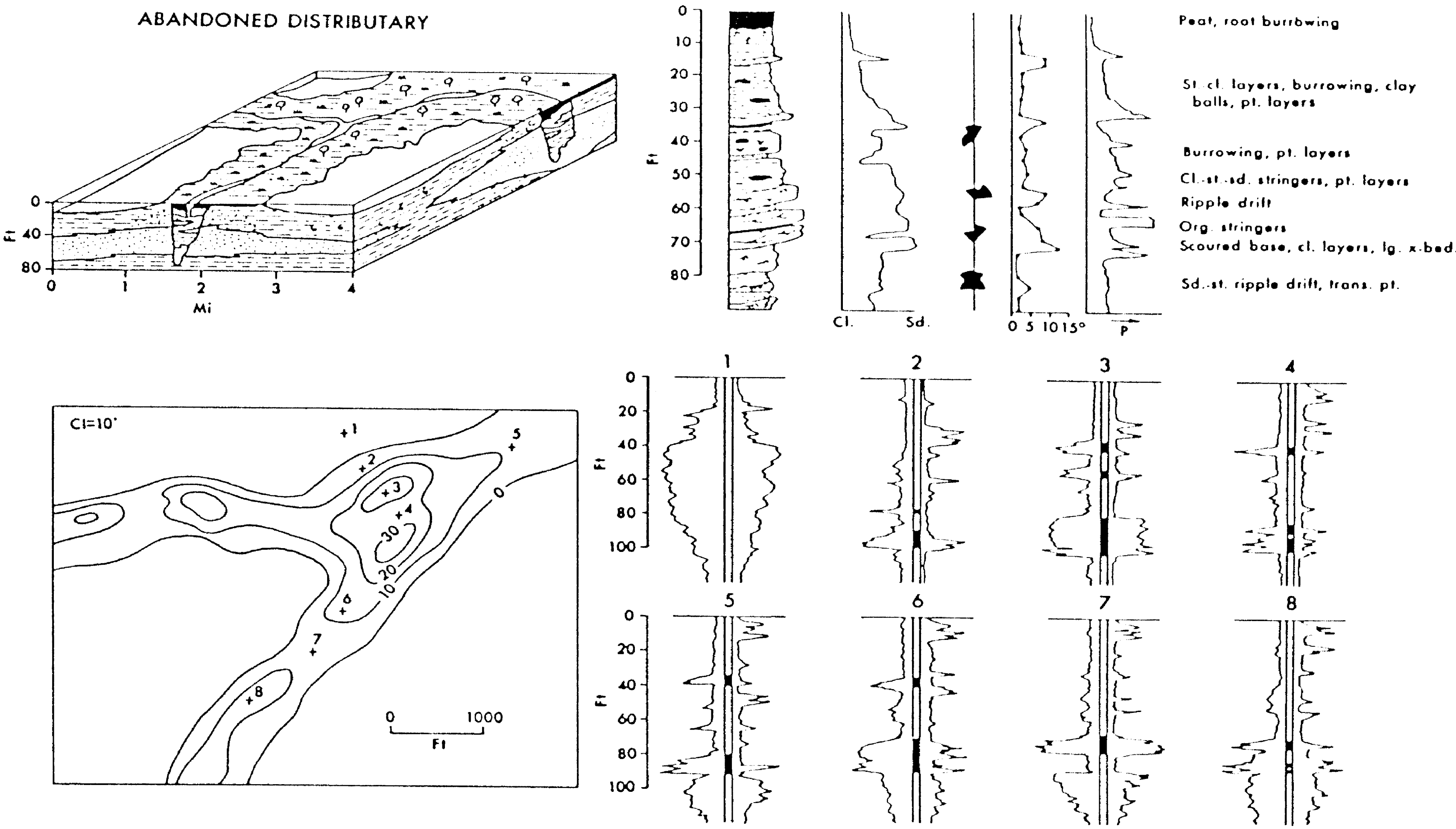


Figure 14. Summary Diagram Illustrating the Major Characteristics of Abandoned Distributary Deposits in the Lower Delta Plain (from Coleman & Prior, 1982).

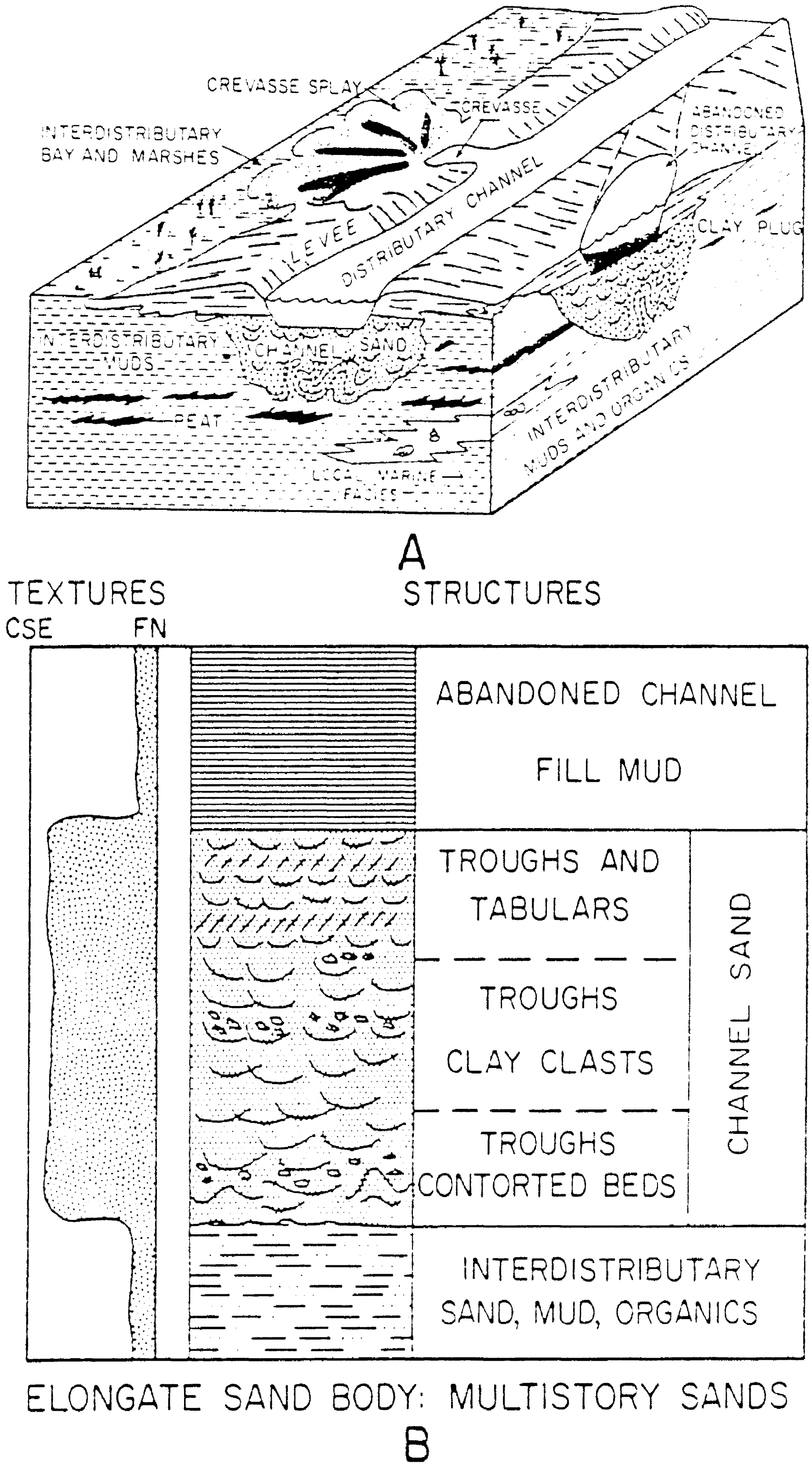


Figure 15. Distributary Channel Model: (A) Block Diagram; (B) Idealized Vertical Sequence in Intracratonic Basins (from Brown, 1979).

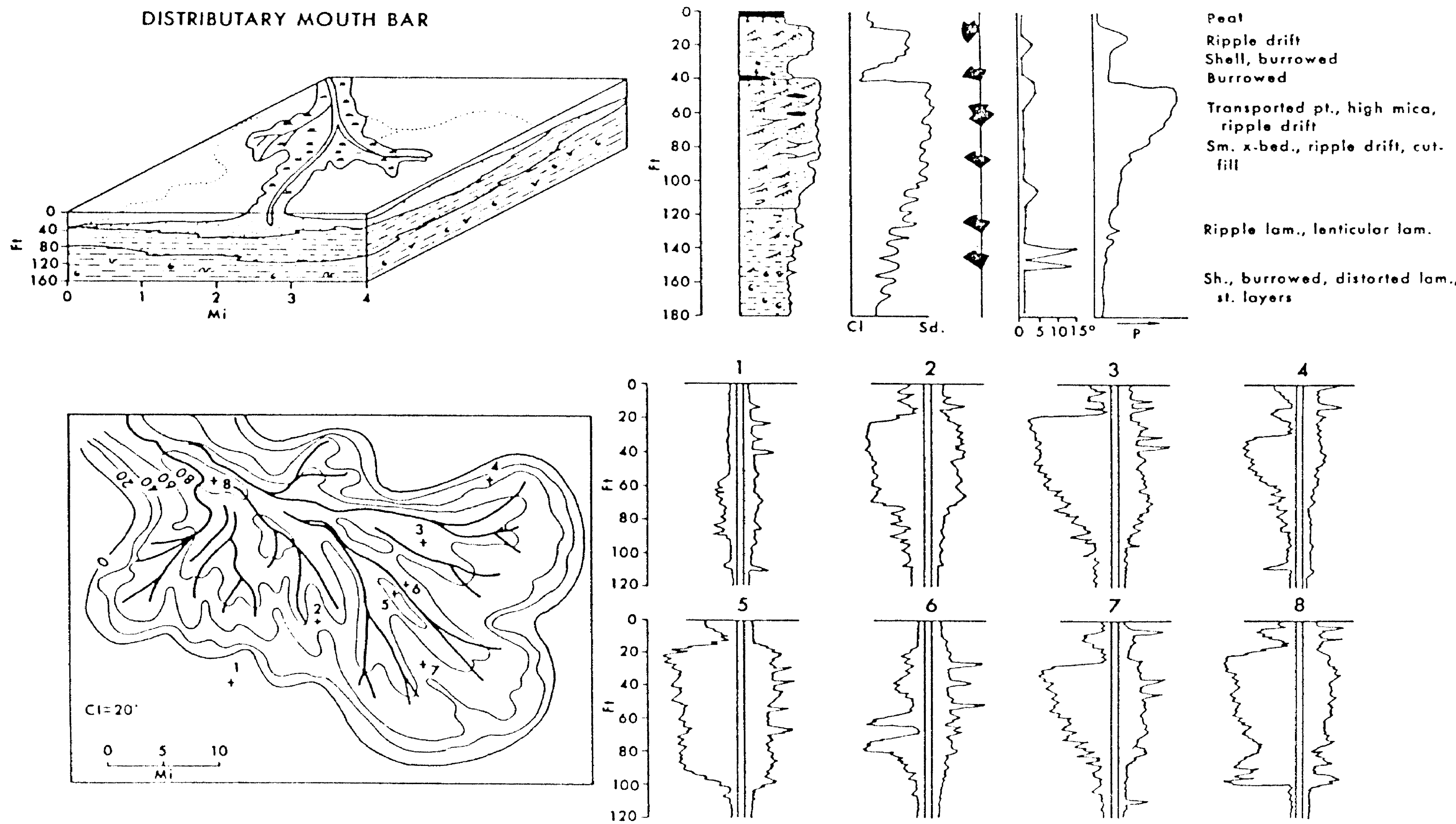


Figure 16. Summary Diagram Illustrating the Major Characteristics of Distributary-Mouth Bar Deposits in the Subaqueous Delta Plain (from Coleman & Prior, 1982).

collectively called the constructional phase of a delta buildup.

Repetitive stratigraphic sequences have long been recognized in ancient and modern deltas. Each complete sequence represents a delta cycle inherent to all deltas (Brown, 1979). The basic vertical sequence is made up of, in ascending order: prodelta shales; delta-front siltstones and sandstones; interdistributary bay and lagoonal shales and siltstones; distributary channel sandstones; reworked delta plain siltstones and limy sandstones; and transgressive shales and limestones. A good illustration of this cycle is of an outcrop of a Desmonesian Series lobate delta sequence in north central Texas studied by Cleaves (1975) (Figure 17).

The delta begins its destructional phase with lobe abandonment. Transgression due to compaction and subsidence permits marine reworking of the previously deposited sediments (Brown, 1979) and deposition of thin limestones (Cleaves, 1984). Brown (1979) provides an idealized delta sequence showing the principle phases, facies descriptions, and electric log patterns for deltas in the Mid-continent (Figure 18).

High-constructive deltas can be divided into two types, on the basis of their overall geometry. The two types are elongate deltas and lobate deltas.

<u>High-Constructive Lobate Delta Geometry</u>. Cratonic lobate deltas usually prograde into shallow water. This

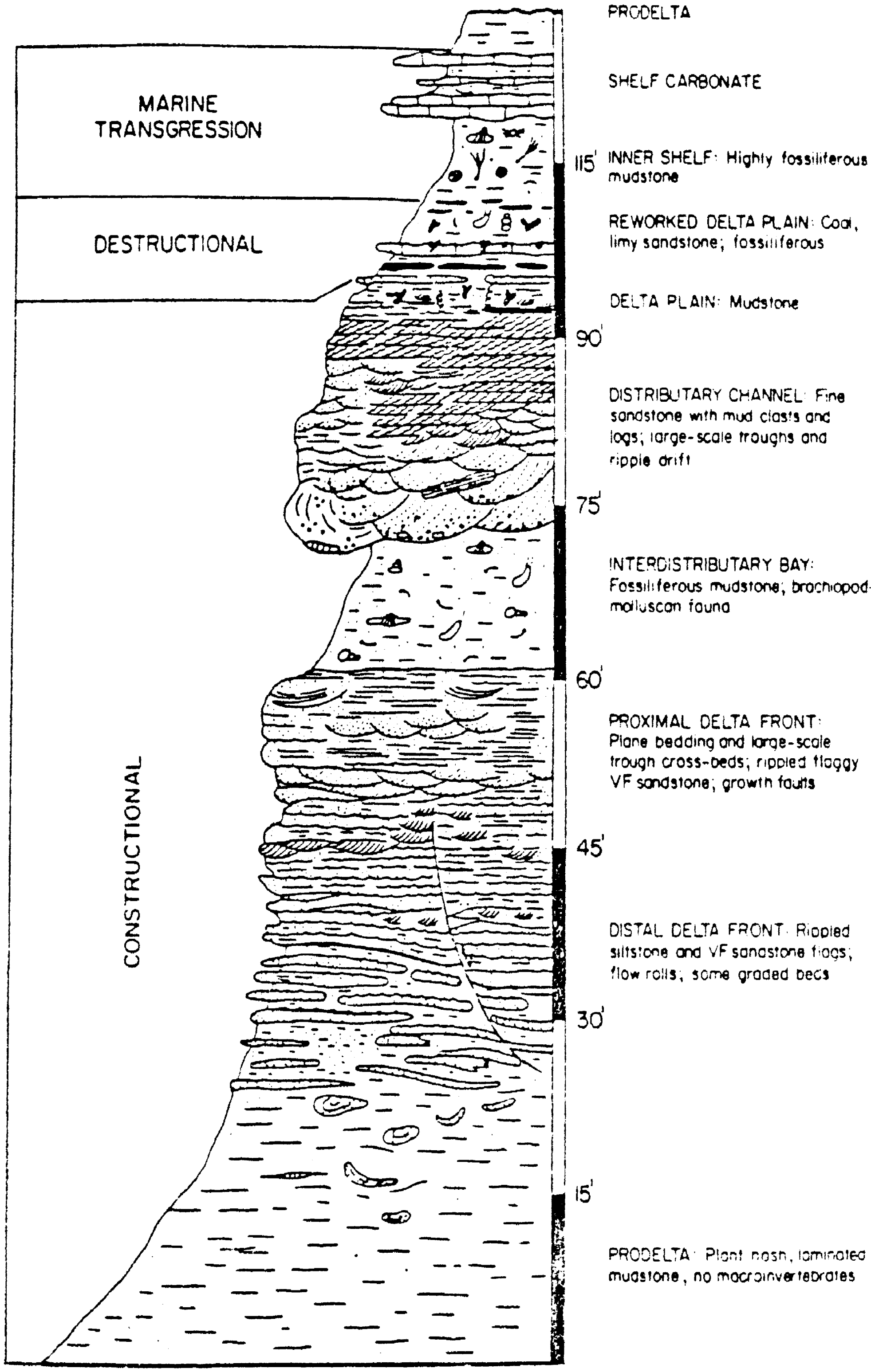


Figure 17. Delta Cycle in Outcrop of Desmoinesian Series Lobate Delta in North Central Texas, Studied by Cleaves (1975) (from Brown, 1979).

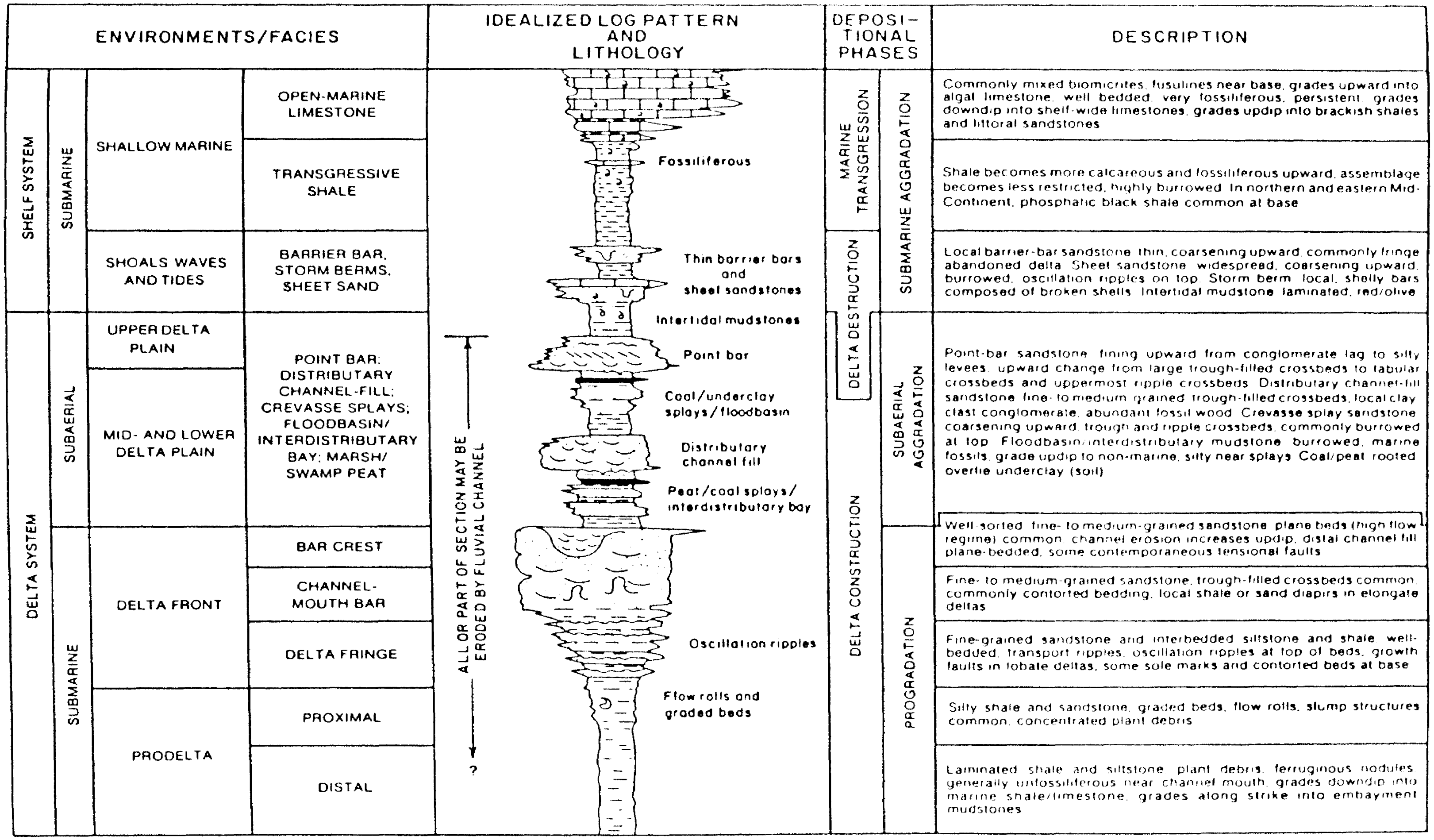


Figure 18. Idealized Cratonic Delta Sequence for Pennsylvanian Sandstones in the Mid-Continent (from Brown, 1979).

type of basin configuration generally prohibits the development of thick prodelta sequences. Thinner prodeltas results in more gradual subsidence, thereby allowing greater reworking by marine processes.

Distributary channels tend to bifurcate readily, resulting in abundant, thin channel facies. In map view, these channels can resemble a braided stream pattern. Stacking of distributary channels in lobate deltas is rare.

This bifurcation of channels tends to allow the distributary-mouth bars to merge, forming what may appear to be a sheet sand in the shallow waters around the periphery of the delta.

Crevasse splays are present, but are not as abundant as in elongate deltas. This is because most distributary channels bifurcate so often that interdistributary bays at any one location are usually short-term features, thereby not allowing extensive crevasse splay development.

Barrier islands and transgressive sheet sands may develop during the destructional phase of the delta.

Growth faults may occur in the delta front facies of lobate deltas, making this facies a primary reservoir target in the search for hydrocarbons (Brown, 1979).

Lobate deltas generally exhibit a digitate coarsening upwards profile (Brown, 1979). Figure 19 illustrates this model with a block diagram. An idealized vertical sequence showing textures and structures present in various facies, and the electric log profile is also shown.

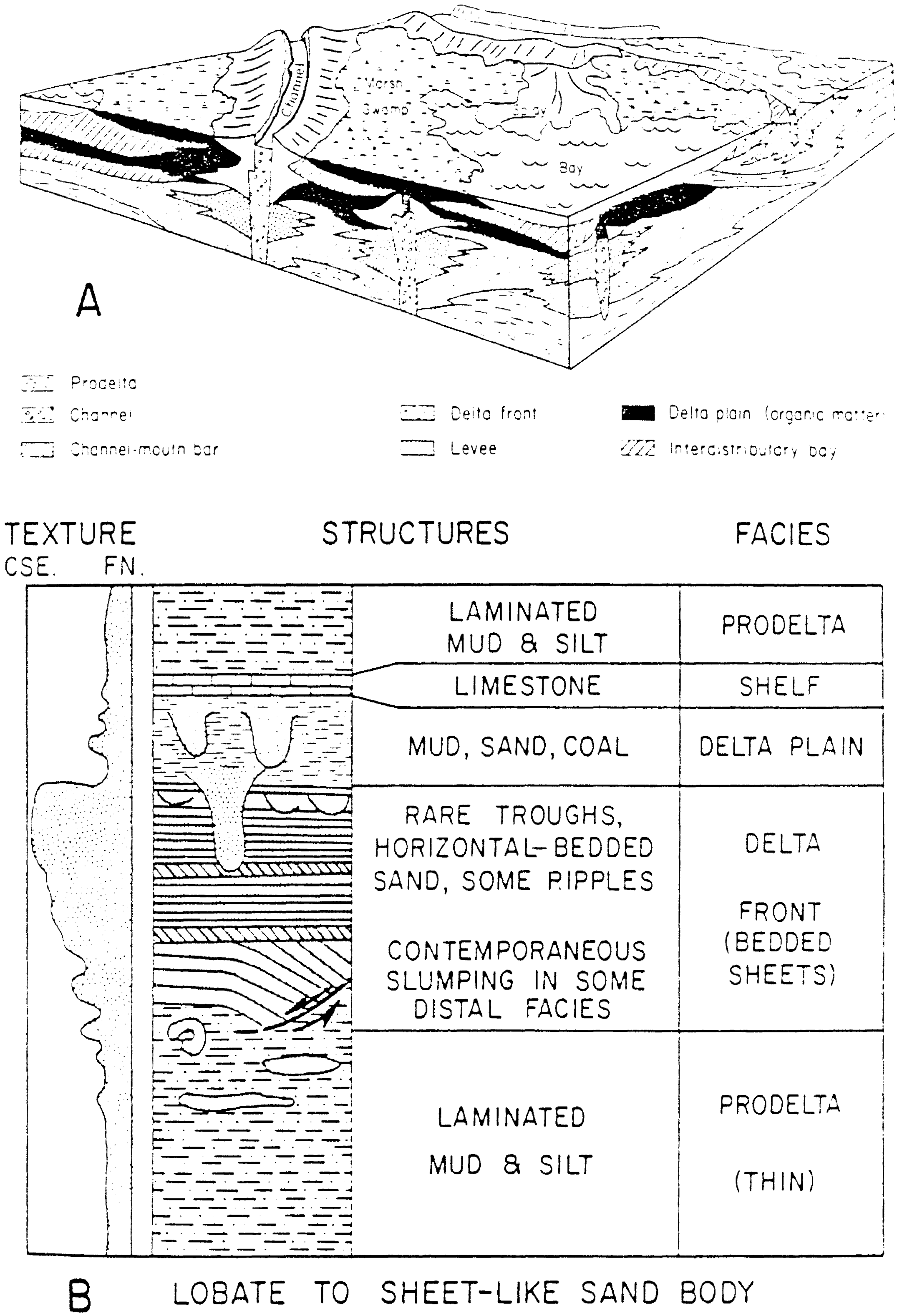


Figure 19. High-Constructive Lobate Delta Model: (A) Block Diagram; (B) Idealized Vertical Sequence in Intracratonic Basins (from Brown, 1979).

High-Constructive Elongate Delta Geometry. The elongate deltas characteristically have high sediment yields that are deposited into relatively deep waters. The basin geometry permits thick prodelta facies to develop, thus allowing for more rapid subsidence and more complete storage of deposited sands. Contemporaneous subsidence of these sands into prodelta muds gives rise to soft sediment deformation, such as contorted bedding and mud diapirism.

Distributary channels are generally straight and do not meander. Stacking of these channels is common. Their stability results from the rapid subsidence into the underlying muds, thus allowing basinward progradation (Cleaves, 1984). Progradation and subsequent development of subaqueous natural levees causes the distributary-mouth bars migrate seaward, in front of the channels creating elongate sand bodies that lie parallel to the distributary channel, or perpendicular to the shoreline.

Delta plain deposits include interdistributary bays and marshes, crevasse splays, natural levees, and point bars. Crevasse splays are common and are considered good traps for hydrocarbons (Cleaves, 1984).

During the destruction phase, delta-front sands may be reworked into barrier islands or strandplains. Extensive peat deposits may be generated in upper delta plain facies.

Elongate deltas usually develop a funnel-shaped, or coarsening up, profile on electric logs (Figure 20). Distributary channels tend to exhibit a blocky profile

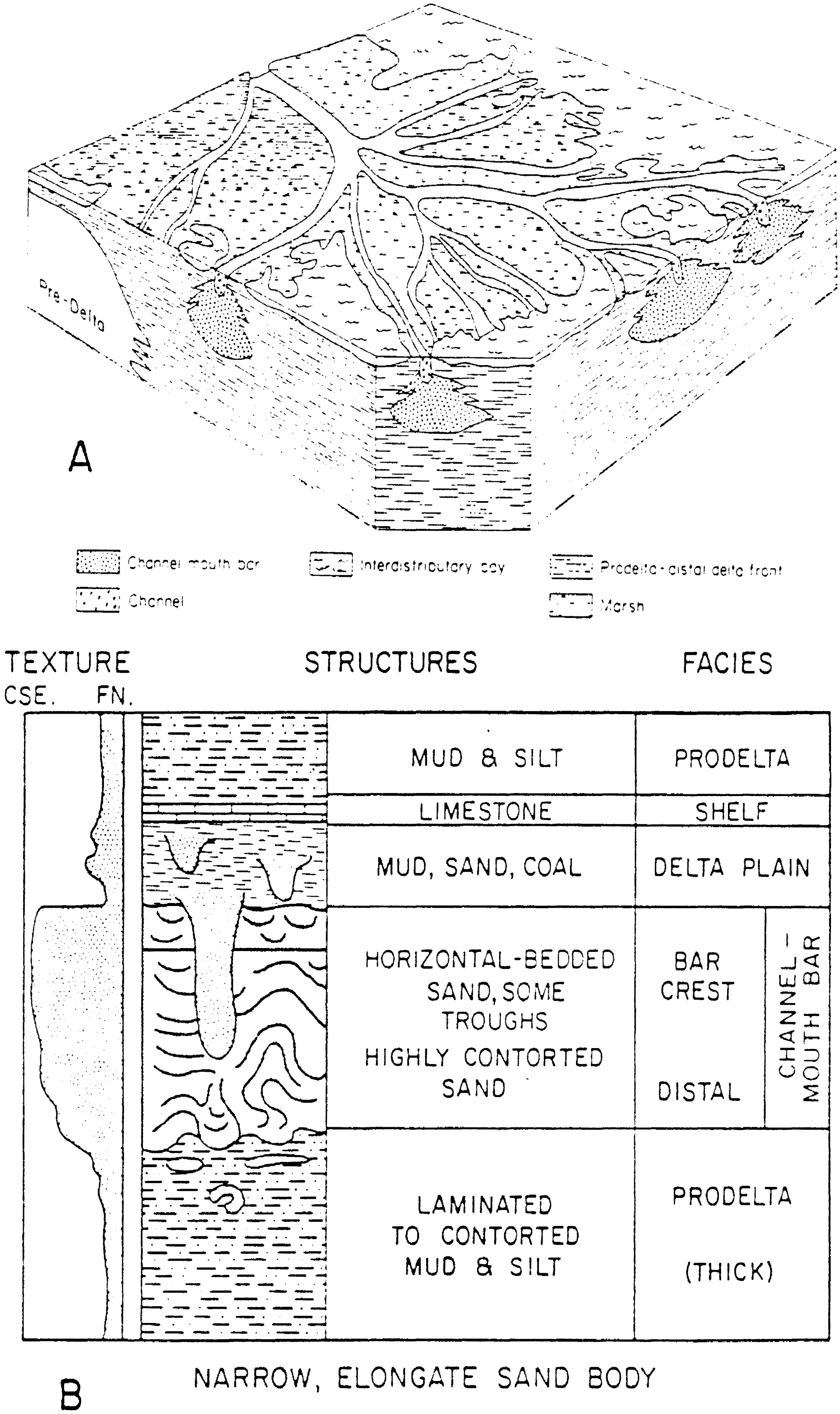


Figure 20. High-Constructive Elongate Delta Model: (A) Block Diagram; (B) Idealized Vertical Sequence in Intracratonic Basins (from Brown, 1979).

(Figure 15). Figure 20 also shows the general structures present in the various facies, as well as a block diagram of an elongate delta.

CHAPTER VI

DISTRIBUTION AND GEOMETRY OF TONKAWA SANDS

Introduction

The following maps were constructed for the study area:

1. Total interval isopach map (Plate III)
2. Net sandstone isolith map (Plate IV)
3. Log map 1 (Plate V)
4. Log map 2 (Plate VIII).

The paleotopographical setting, or basin configuration, in the study area was reconstructed with the isopach map. General sand thickness trends were also delineated with this map. Determination of sandstone body geometry and trends was facilitated by the preparation of the net sandstone map, thereby allowing interpretations of various depositional environments to be made. The log maps are useful in delineating trends as well as in estimating edges of sandstone bodies (Shelton, 1972). Log map 2 is very helpful in this respect. The primary use of Log Map 1, however, is to illustrate the characteristic log shapes of the interval over the study area. The reason for this is that electric logs on this map is much wider spaced than Log Map 2, thereby greatly decreasing the amount of detail regarding sand distributions.

Total Interval Isopach Map

The isopach map shows a southward sloping paleotopography in the study area. This configuration is the result of terrigenous clastic sediments having onlapped onto marine carbonates in a shelf tectonic setting and should not be confused with a true slope depositional environment.

Thicknesses for the total format interval range from over 420 feet in the extreme southeast and southwest parts of the study area to less than 160 feet in the northwest. There is an overall thinning trend to the north and northwest toward the carbonate bank, showing the pinching out of the interval. The carbonate shelf was positioned where reliable determinations of marker beds and of the sand bodies within the interval could not be made. The thinning relationship with the carbonate bank is clearly illustrated in cross sections A-A' and B-B' (Plate I).

Areas of local thickening are apparent throughout the mapped area (eg. northwest part of T26N-R14W, central and east part of T27N-R16W). These anomalous features parallel the contours and trend in a general northeast-southwest direction. This thickening is, at least in part, due to differential compaction of the sandstones and shales (Busch and Link, 1985). The continuity of these trends suggests elongate sand bodies.

Net Sandstone Isolith Map

This map is a compilation of all the sand bodies identified in the Tonkawa format. Thicknesses in the study area range from 0 to greater than 140 feet, and average roughly 35 to 40 feet. The thicker sands are generally in the southeast part of the mapped area, where the average thickness is about 60 feet. Anomalously thick sands of over 100 feet are present in the south central area (T25-26N, R15-16W). The sands to the north are thinner and are separated by shaly areas with no sand deposition.

When studying electric logs separately or in conjunction with regional cross sections and maps, the Tonkawa sands commonly have a sheet-like appearance. At first glance, the southern two-thirds of the mapped area also give this impression. This sheet-like geometry has led some workers to interpret marine environments of deposition. If, however, one carefully contours the thickness values in conjunction with the isopach map and the detailed cross sections, a definite trend develops. These sand trends are consistent with the isopach map in that they too indicate a northeast-southwest orientation. Closer observation shows that the thicknesses within these trends decrease in the southwest direction, thereby implying a northeast source area.

The morphology of the sands indicate that the sediments in this area were deposited in a high-constructive lobate delta system. The patterns of the thick sands show what can be interpreted as highly bifurcating distributary channels.

The sheet-like geometry for the sandstone isolith is most likely caused by the merging of distributary-mouth bar deposits associated with bifurcating distributaries in an advancing delta lobe. This type of deposit is also indigenous to areas with extremely low slope angles and where tidal range is low (Coleman & Prior, 1980). Waves may have also reworked the sands to some degree (Brown, 1979; Cleaves, 1984). Corresponding electric logs tend to show a coarsening upward pattern at the base. The shaly areas between the sand bodies are probably interdistributary bay type environments, indicating periods of nondeposition of coarse clastics.

The anomalously thick sands mentioned above trend almost perpendicular to the major trend exhibited by the rest of the sands. Cross section D-D' (Plate VII) shows a rapid thickening and thinning of the sands in this area. The corresponding electric log signatures suggest stacked sands, perhaps distributary-mouth bars and/or channel deposits (Figure 15).

Figure 7 (cross section D-D') illustrates, more specifically, the thickening of the "A" package sands in this location. Cross sections G-G' and H-H' (Plate VIII) were prepared from closely spaced wells across this area give a more detailed view of the thickening of this package. Log map 2 (Plate VIII) shows the distribution and implied trend of the "A" sands with respect to the overlying sands.

The trends of the overlying sands were omitted since they have already been determined.

The trend exhibited by this package is in a general southeast-northwest direction, suggesting a southeast source area. An argument could be made for a northeast-southwest trend if one assumes that all the other "A" package sands were eroded, however, no evidence is presently available to substantiate this hypothesis. Furthermore, since thicknesses increase to the south and southeast, it would be logical to think that these deeper sands would be present in those areas.

Several workers (Lukert, 1949; Lins, 1950; Winchell, 1957; Sanders, 1959; and Griffith, 1983) have suggested that the lower boundary of the Tonkawa interval is marked by an erosional contact which occurs at the base of the lowest sand body. The evidence for this is in outcrops of Tonkawa sediments deposited by fluvial processes in northeast and north-central Kansas. Disconformities of this type, however, has no regional significance since all channels have disconformities at their base. But their inferences do warrant some consideration since the Virgilian Tonkawa sands do rest on Missourian limestones.

All in all, the possibility that an unconformity in this area remains. If one does, then the base of the Tonkawa interval would be higher in the stratigraphic section than the top of the Avant limestone. The resulting interval configuration would correspond to GIS profile C

(Figure 4). Furthermore, the "A" package sand would be a Missourian deposit in another interval. But, until sound evidence has been presented to lend credence to this hypothesis, the "A" package sands will be included as part of the Tonkawa format.

Log Map 1

One hundred fifteen electric logs were used in the construction of this map. Contour lines have been added to illustrate the sand trends and to distinguish between the thicker and thinner sands. Although its main purpose is to show general log characteristics in the study area, close observation will reveal the general limits of the sands in each package.

The cross sections (Plates I & II), and Figures 6 and 7 show that each successive sand package extends farther northward than the underlying group. The log map also illustrates this trend. Apparently, the basinal area filled with time, thereby allowing the delta to migrate laterally towards the carbonate shelf area.

The distribution of sands in this study, when shown with those mapped by others, supports the idea of a fluvial-deltaic system being responsible for the deposition of the Tonkawa sands (Figure 21).

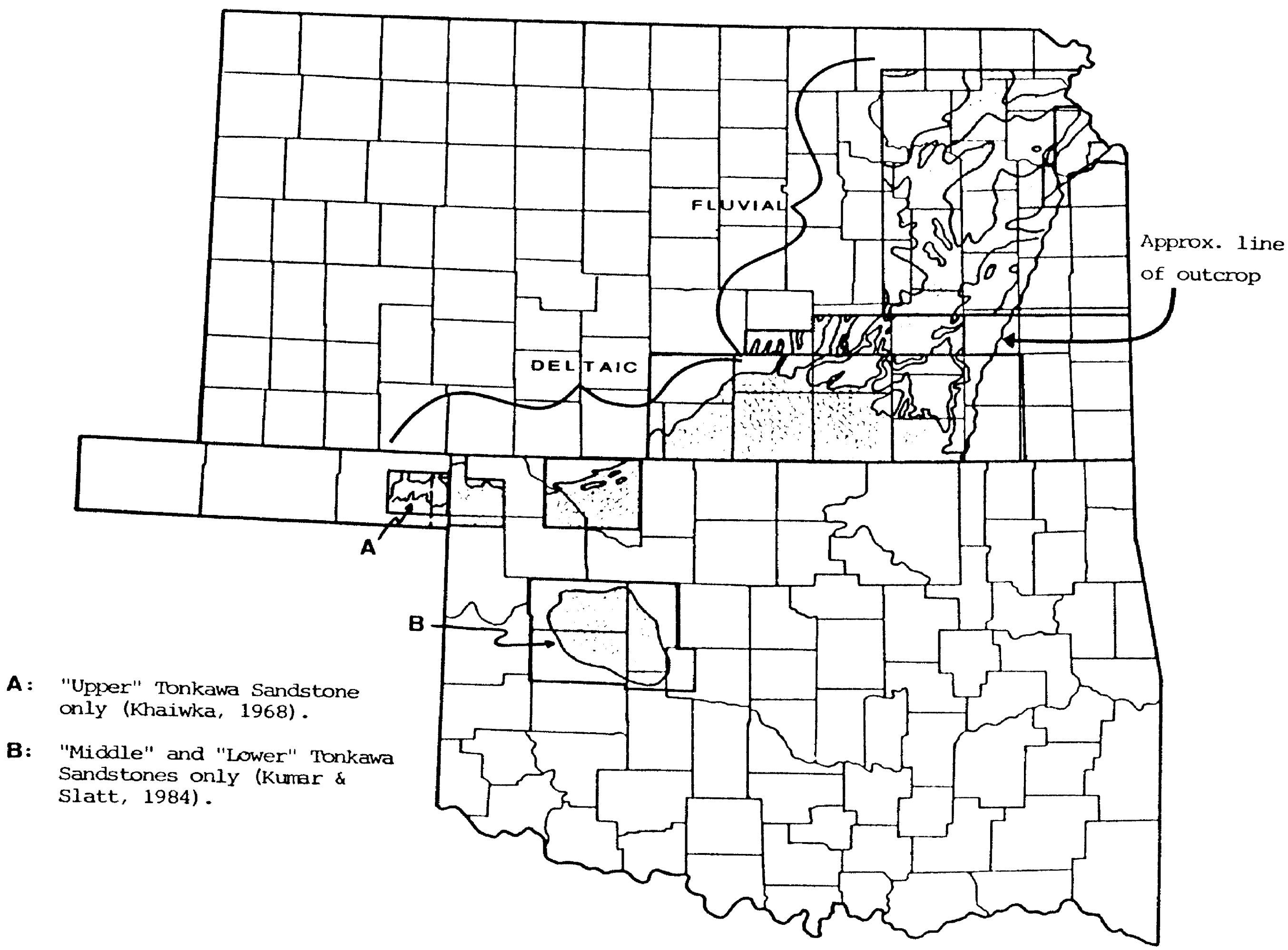


Figure 21. Distribution of Tonkawa Sands in Kansas and Oklahoma (Kansas section, modified from Griffith, 1981) .

CHAPTER VII

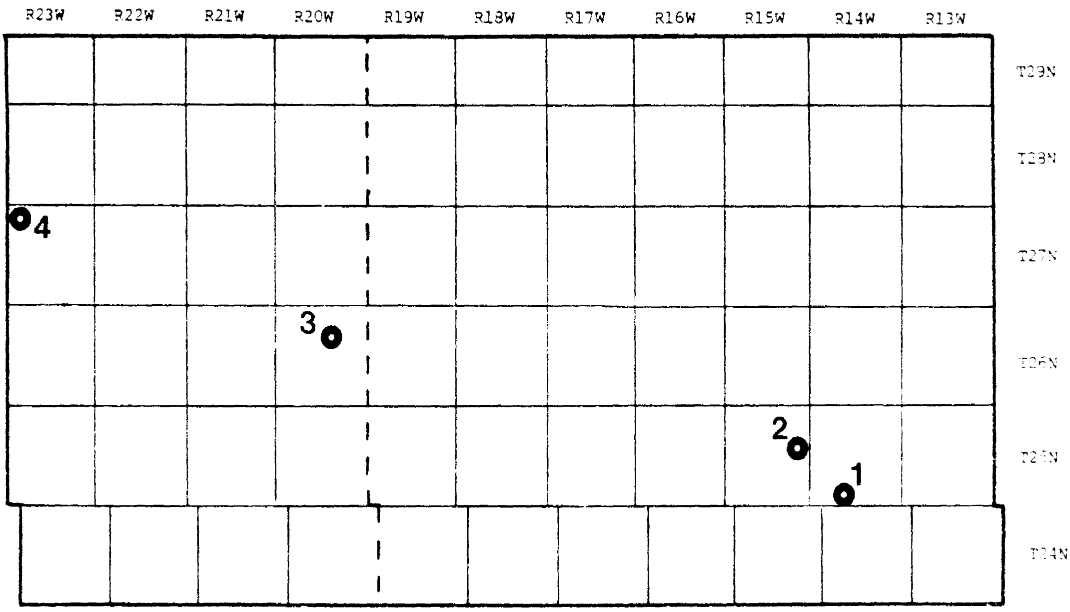
FACIES ANALYSIS

Introduction

Cores of parts of the Tonkawa format from four wells were studied in detail (Figure 22). One of the main objectives of this study was to affix possible depositional environments to the various facies present in each of the cores. Restivity-sp electric log signatures of the Tonkawa format for these wells is shown on Figure 23. See Figure 24 for an explanation of the symbols used for the lithologies and contacts displayed on the core logs.

The only other work known to have been done on cores from the Tonkawa interval was by Walton and Griffith (1983), in which they described a core from Harper County, Kansas (20-T37S-R8W), and Kumar and Slatt (1984), on two cores in Dewey and Custer Counties, Oklahoma. Kumar & Slatt (1984) interpretate these cores as being of slope and submarine fan facies, but do not provide a detailed log or a complete set of photos in their report. Walton and Griffith (1983), on the other hand, describe the TXO Robinson C-1 core as being a deltaic sequence. They also provide photos and a detailed log of the core.

The reasoning they used for a deltaic interpretation



CORE LOCATIONS

1. Gulf Oil Corporation #1 Shade	31 - T25N - R14W C-SE-SW
2. Earlsboro Oil & Gas Co. #1 Curtis-Stark	20 - T25N - R15W C-SE-NE
*3. Shell Oil Company #1 Waits	12 - T26N - R20W C-SW-NE
*4. Southland Royalty #1 Crawford	34 - T27N - R23W E-NW-NW

* Outside study area

Figure 22. Well Names and Locations of Cores Analyzed in This Study.

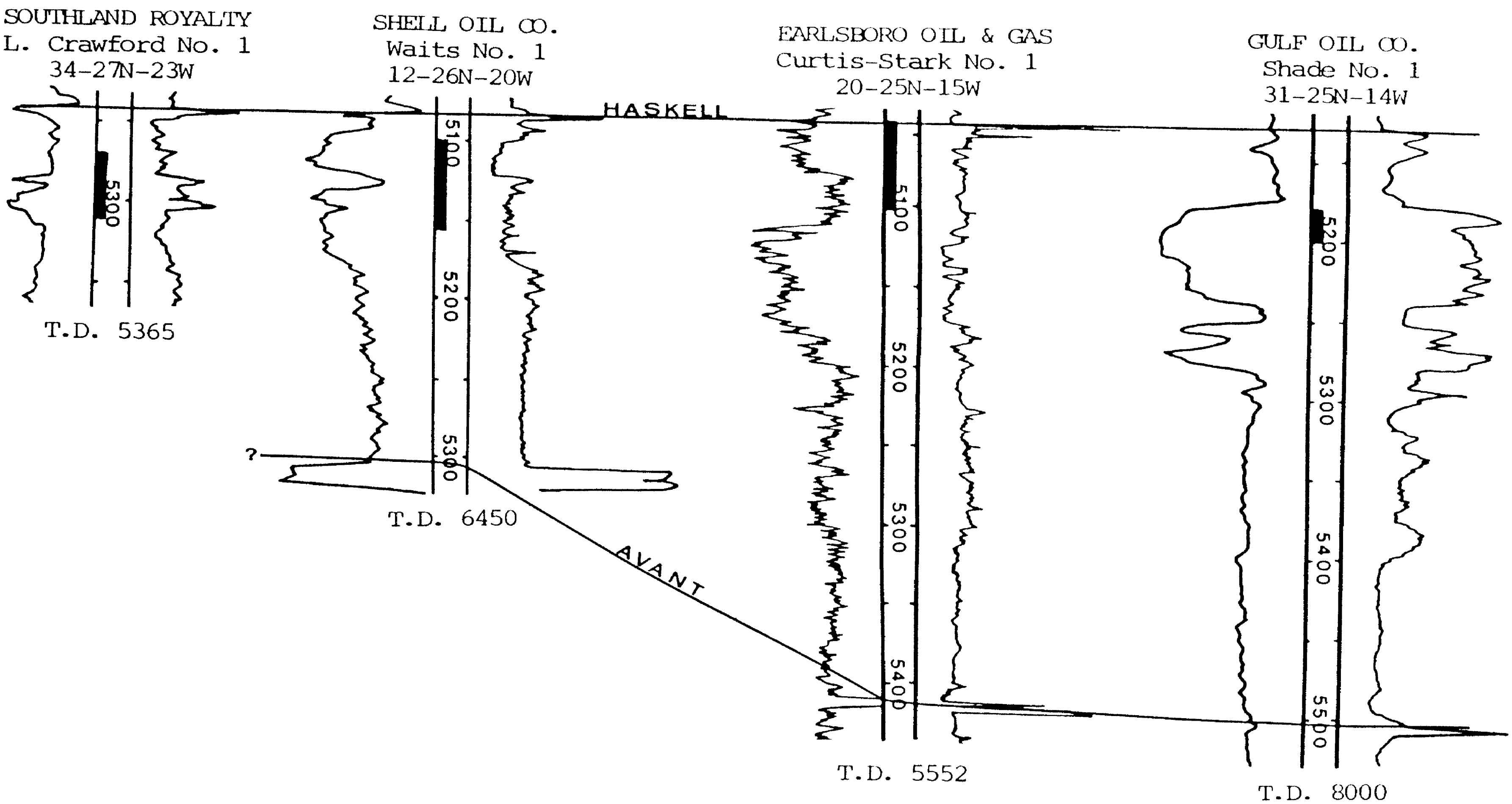


Figure 23. Electric Logs of Tonkawa Format from Cored Wells.

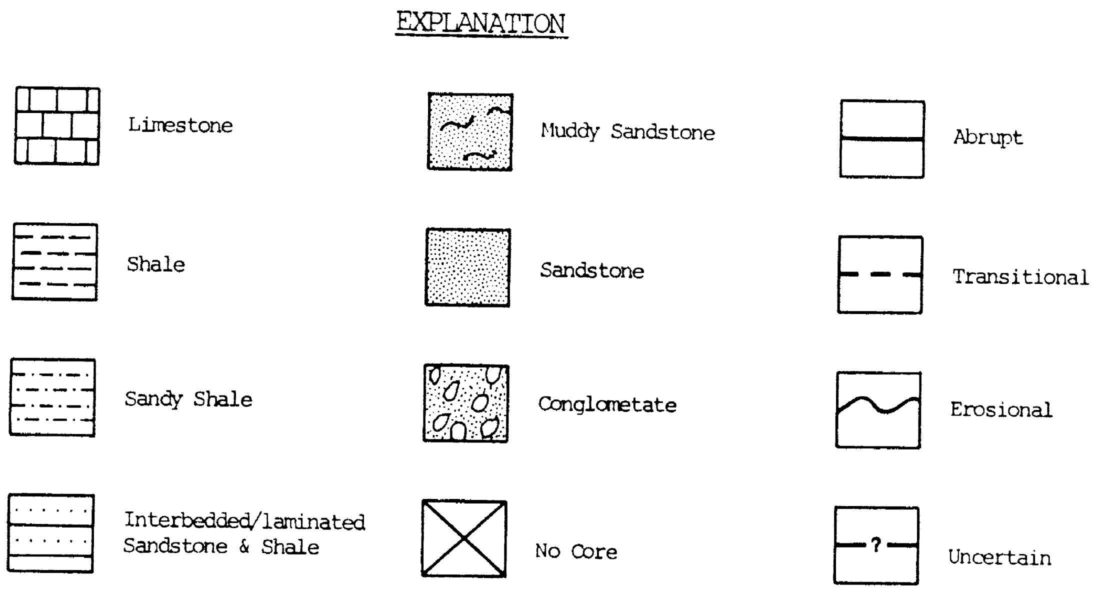


Figure 24. Explanation of Symbols Used for Lithologies and Contacts on Core Logs.

includes: 1) the interbedding of terrigenous and marine sediments, which can be broken down into representative marine and fluvial processes and sequences known to exist in prograding deltaic environments; and 2) rapid deposition as indicated by a lack of burrowing in the fine grained facies. They also state that there was episodic sedimentation that formed small scale, fining upward packets grouped into larger coarsening upward packages. These sequences were repetitive, suggesting that environments were adjacent to each other and were controlled by water depth and sediment input rate (Walton & Griffith, 1983). The sand to shale ratio increases upward indicating a prograding delta. The data suggest deposition in a marine margin area where lateral conditions were changing quickly over a short period of time. These changes were progressive and resulted in rapid accumulation, such as those found in a deltaic environment.

This review of their report is particularly interesting because it coincides with many of the conclusions formulated while examining the cores in this study.

Core Descriptions

Gulf Oil Corporation, Shade No. 1

This well is located in the Northeast Waynoka Field in Woods County (31-T25N-R14W). It was completed on January 1, 1957 to a depth of 8000 feet. A drill stem test of the interval 5174-5201 operated for one hour recorded 129 feet of slight gas cut mud and 1040 feet salt water, with the bottom hole formation pressure ranging from 80-580 PSI.

The cored interval ranges in depth from 5178-5201 feet and contains one continuous, thinly bedded sandstone unit (Figures 25 and 26A). The sand is very fine-grained except for the bottom two feet of the core, where the sand becomes fine-grained. Shale flasers are scattered throughout. Some of these have been replaced by siderite. Bedding is essentially horizontal; thin laminations are wavy. Clay clasts are present just above 5200 feet, indicating a possible erosive episode. Small scale trough cross-bedding is the dominant bedform (Figure 26B). However, there are some planar cross-beds as well as thin horizontal plane beds. These features indicate a moderate to high flow regime.

Flowage deformation features are also present in the core. These small scale features are actually slightly convolute bedding structures which formed due to current induced deformation and subsequent rapid burial.

Porosity values, taken from petrographic studies, range from a low of 9% at 5191 feet to a high of 14% at 5181 feet, with an average of 11.5%. A trend does develop in which the porosity shows an increase with decreasing depth. This is readily apparent above 5191 feet.

The Sp-curve reflects a coarsening of grain size or decrease in mud content with depth to 5210 feet (Figure 23). Below this depth, the curve decreases somewhat, suggesting

Company: Gulf Oil Corporation
Location: C-SE-SW Sec. 31 T. 25N R. 14W
Well: Shade No. 1
Stratigraphic Unit: Tonkawa
County: Woods State: Oklahoma
Age: Virgilian (upper Pennsylvanian)

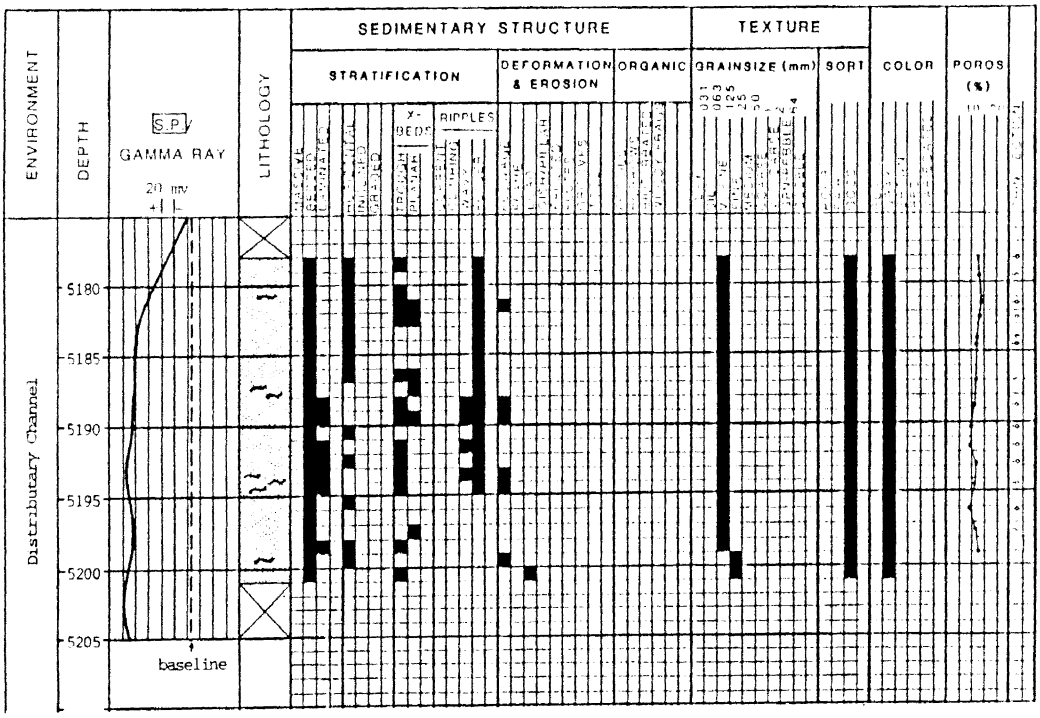
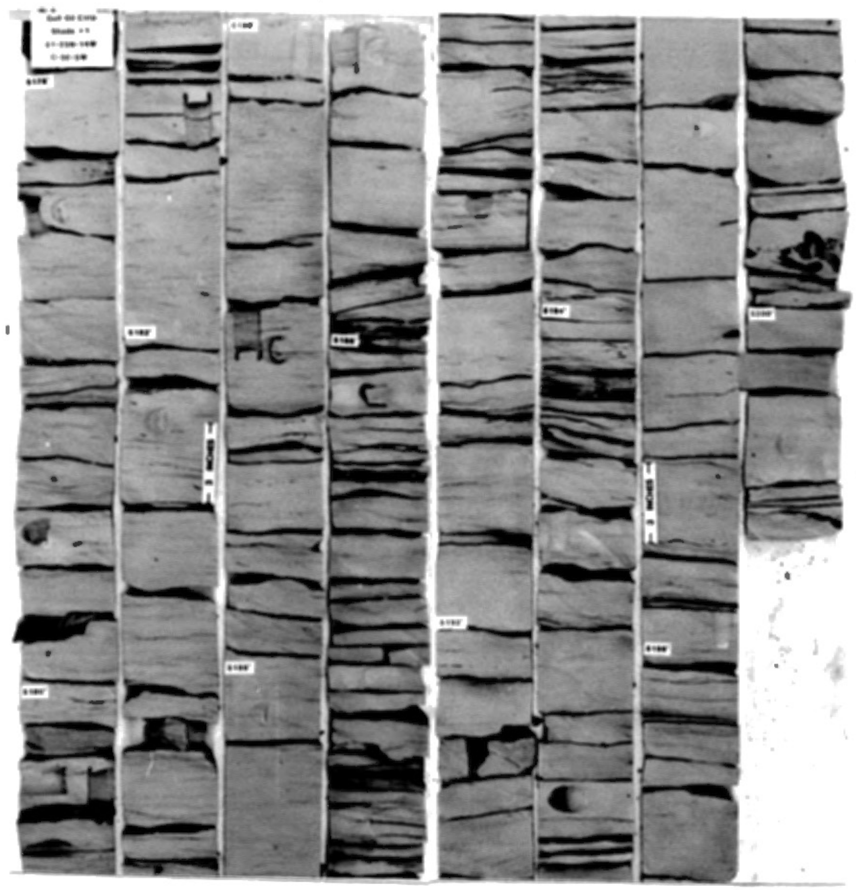


Figure 25. Log of Gulf Oil Corp., Shade No. 1 Core.

(A)



(B)

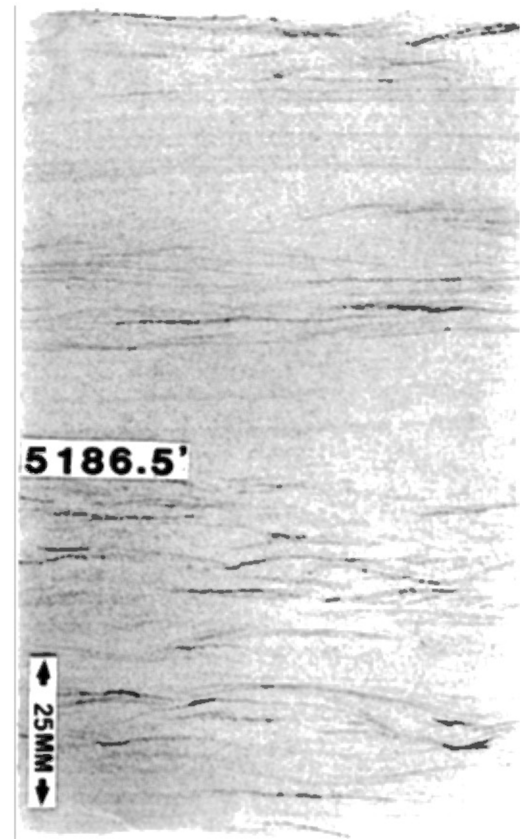


Figure 26. Photograph of Gulf Oil Corp., Shade No. 1 Core: (A) Total Cored Interval; (B) Small Scale Trough and Planar Cross Bedding, Horizontal Bedding, and Flasers.

either decreasing grainsize or a lack of porosity due to diagenetic controls. The curve also has rather abrupt contacts at the top and base of the unit, indicating sudden changes in the sediment size. Based on this log signature character and from the sedimentologic features previously discussed, the core has been interpreted as being part of either a distributary channel or distributary-mouth bar facies.

Earlsboro Oil & Gas Corporation,
Curtis-Stark No. 1

This well was also drilled in the Northeast Waynoka Field (20-T25N-R15W), about 4.7 miles northwest of the Gulf Oil Co, Shade No. 1 well. It was completed on July 23, 1970 to a depth of 5552 feet. No drill stem tests were performed in the Tonkawa interval.

The cored interval ranges in depth from 5055-5113 feet and contains approximately 61 feet of sand and shale and 2 feet of limestone (Figure 27). Figure 28 shows a photograph of all but the lower ten feet of the core.

The core itself can be divided into 6 intervals representing four different facies. As is the case of the core examined by Walton & Griffith (1983), these facies are all related and can be broken down into sequences representative of marine and fluvial processes known to exist in prograding deltaic environments.

The lowermost interval (5102-5113') is comprised of

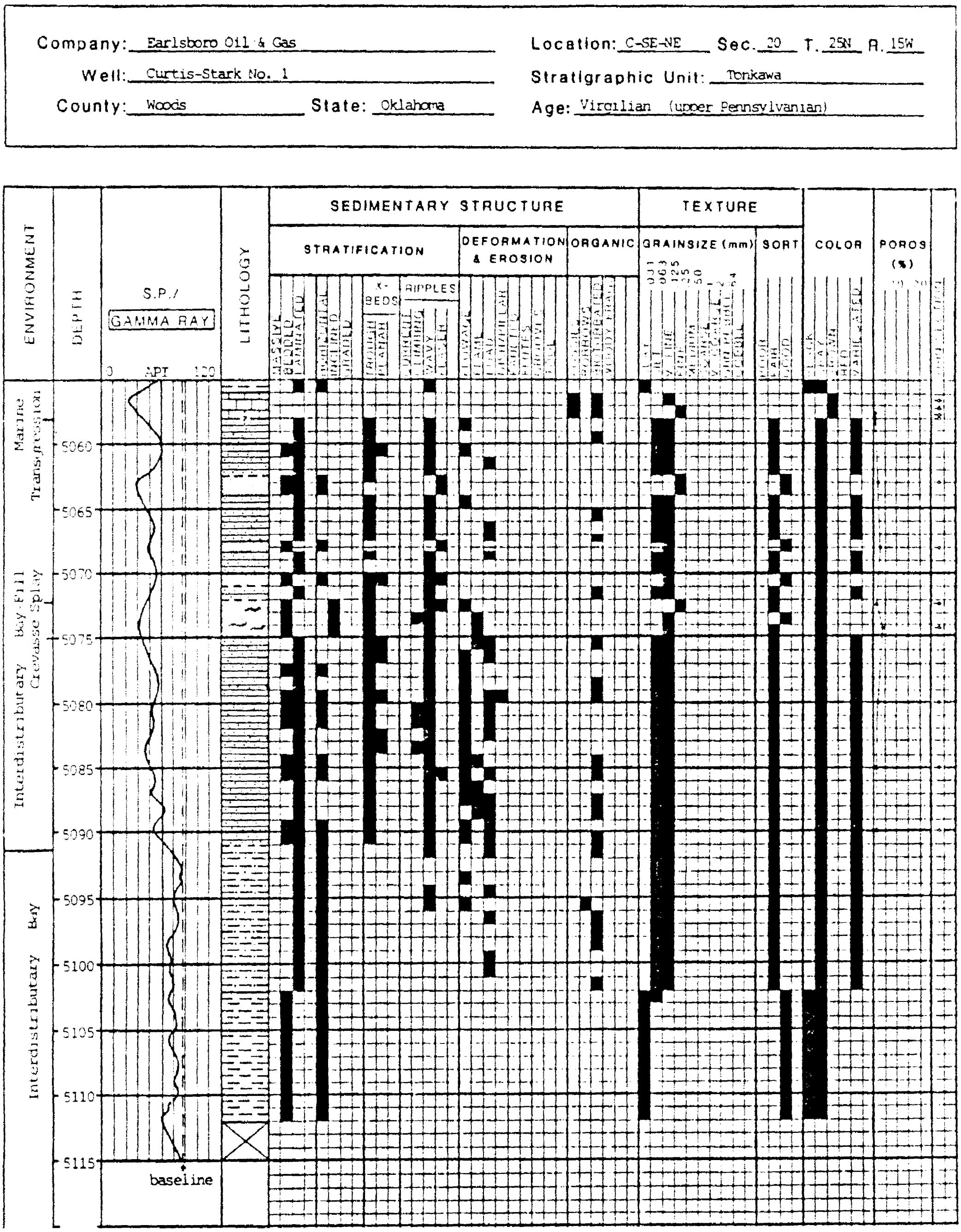


Figure 27. Log of Earlsboro Oil & Gas Corp., Curtis-Stark No. 1 Core

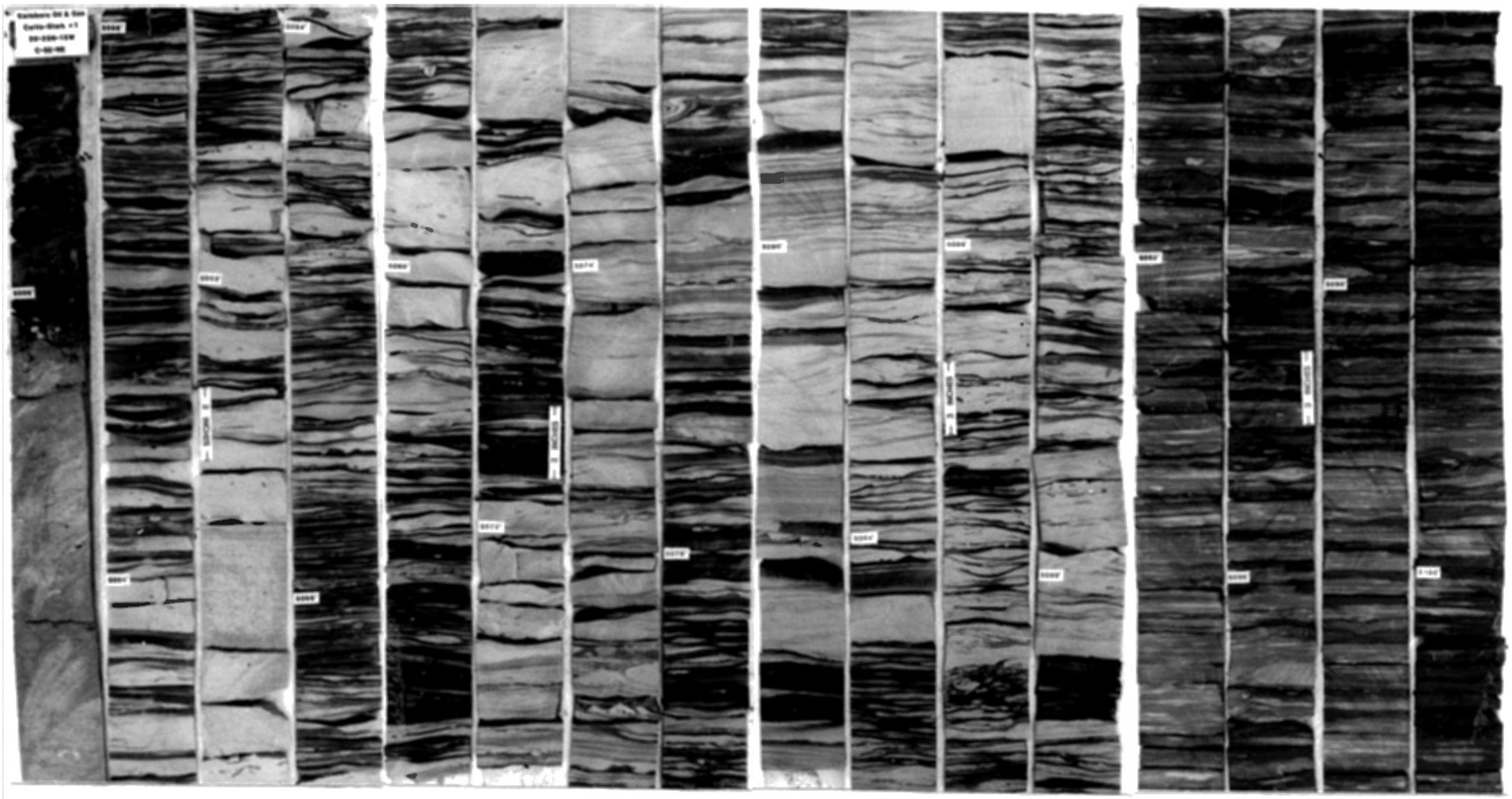


Figure 28. Photograph of Earlsboro Oil & Gas Corp., Curtis-Stark No. 1 Core.

thinly bedded dark gray-black shale. No deformation or bioturbation features were noted in this section. A gradational contact marks the upper limit of the unit.

Strata between 5091' and 5102' (interval 2) are a variegated gray, horizontally laminated, sandy shale unit displaying minor load and flowage deformation features. Scattered bioturbation is also present in this interval. Burrowing is present at 5096'. This unit grades into the overlying strata (interval 3).

Interval 3 occupies 5075-5091' and is composed of a variegated gray, wavy interlaminated sandstone and siltstone sequence interrupted by thin sandstone beds. The sands are all very fine-grained and contain predominantly small scale trough cross-bedding (Figure 29A). Some planar cross-bedding and climbing ripples are also present, but to a much lesser extent (Figure 29B). Deformation features consist of mainly flowage/convolute bedding and load structures. A few flame structures are also present in this interval (Figure 29C). Small bioturbation features are located in those areas where there is an increase in the siltstone/sandstone ratio. These areas are indicative of periods of relative quiescence and slower sedimentation rates.

A gradational contact separates interval 4 from the lower interval. This section of strata is a three foot unit (5072-5075') of gray, very fine-grained sandstone with occasional shale flasers. Bedding in this sand is inclined at a low angle. Within these beds are trough cross-bedding

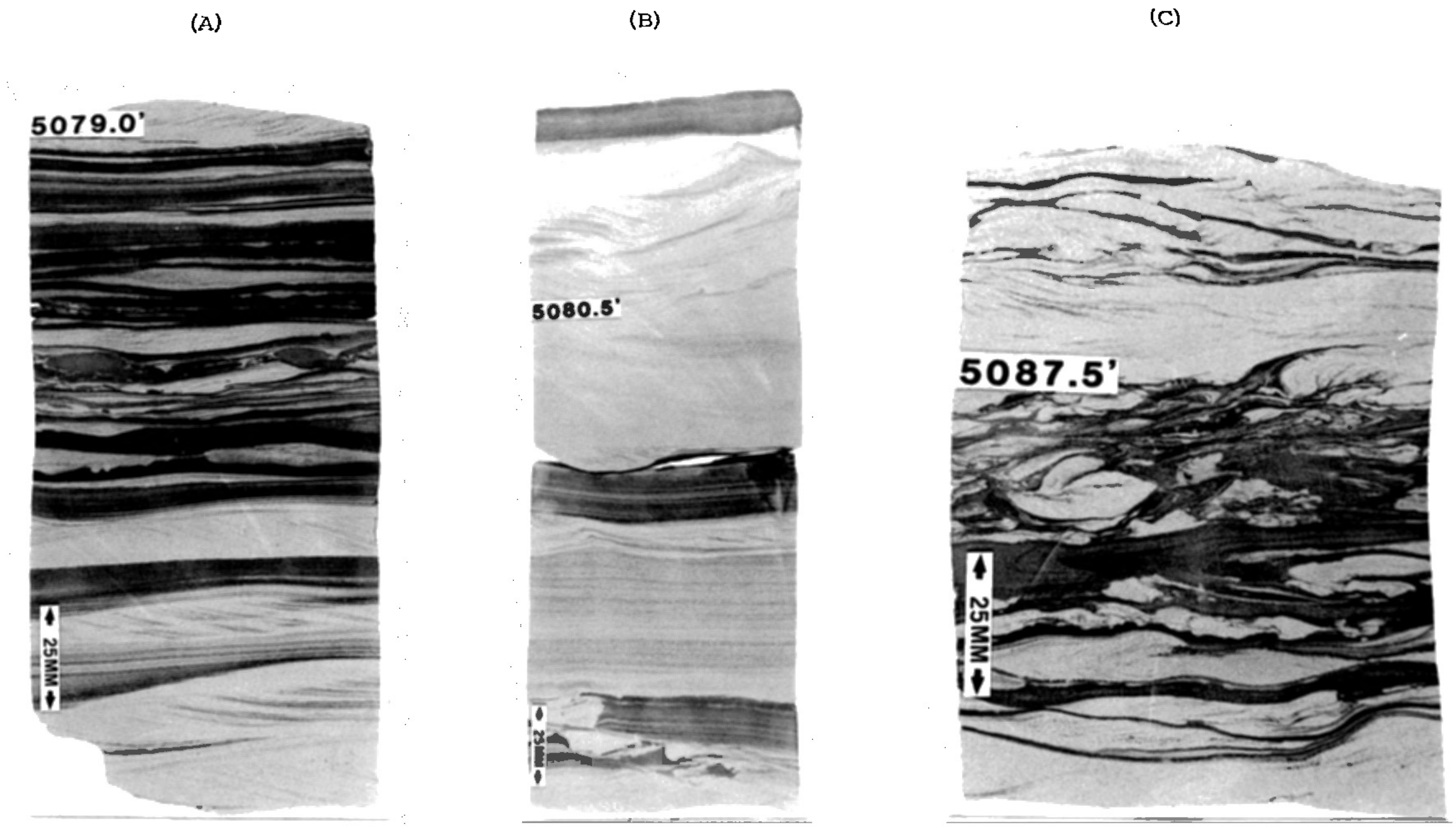


Figure 29. Photograph of Earlsboro Oil & Gas Corp., Curtis-Stark No. 1 Core: (A) Small Scale Trough and Planar Cross Bedding, Sideritized Clay Clasts, and Ripples; (B) Climbing Ripples and Load Deformation; (C) Flame Structure and Flowage Deformation.

and climbing ripple stratification, indicating rapid deposition. A few flowage deformation features and flame structures are also present. The upper contact of this interval is abrupt.

Interval 5 occupies fourteen feet of strata between 5058' and 5072'. This unit is a predominantly variegated gray, wavy interlaminated sandstone/siltstone with thin horizontal beds of very fine sandstone. These sandstone beds are less than 1.5' in thickness, contain abundant flasers, and display mostly horizontal bedding. Trough cross-bedding is the dominant stratification feature through the rest of the interval. Small flowage and load deformation features are also present, as well as a few minor bioturbation structures.

The uppermost section of the core, interval 6, marks the upper transgressive phase of the Tonkawa format. This unit is the Haskell Limestone, which is actually a two foot thick, brown, fossiliferous algal boundstone that grades downward into a very sandy limestone (Figure 30). Fossils tend to be larger and more complete in the lower section. These fine upward, indicating a decrease in energy. This corresponds to a decrease in sand content and subsequent increase in algal content, which normally indicates a decrease in the flow regime. Fossils present include brachiopods, crinoids, bryozoans, echinoids, and corals. The coral fragments are restricted to the top of the section.

(A) (B)

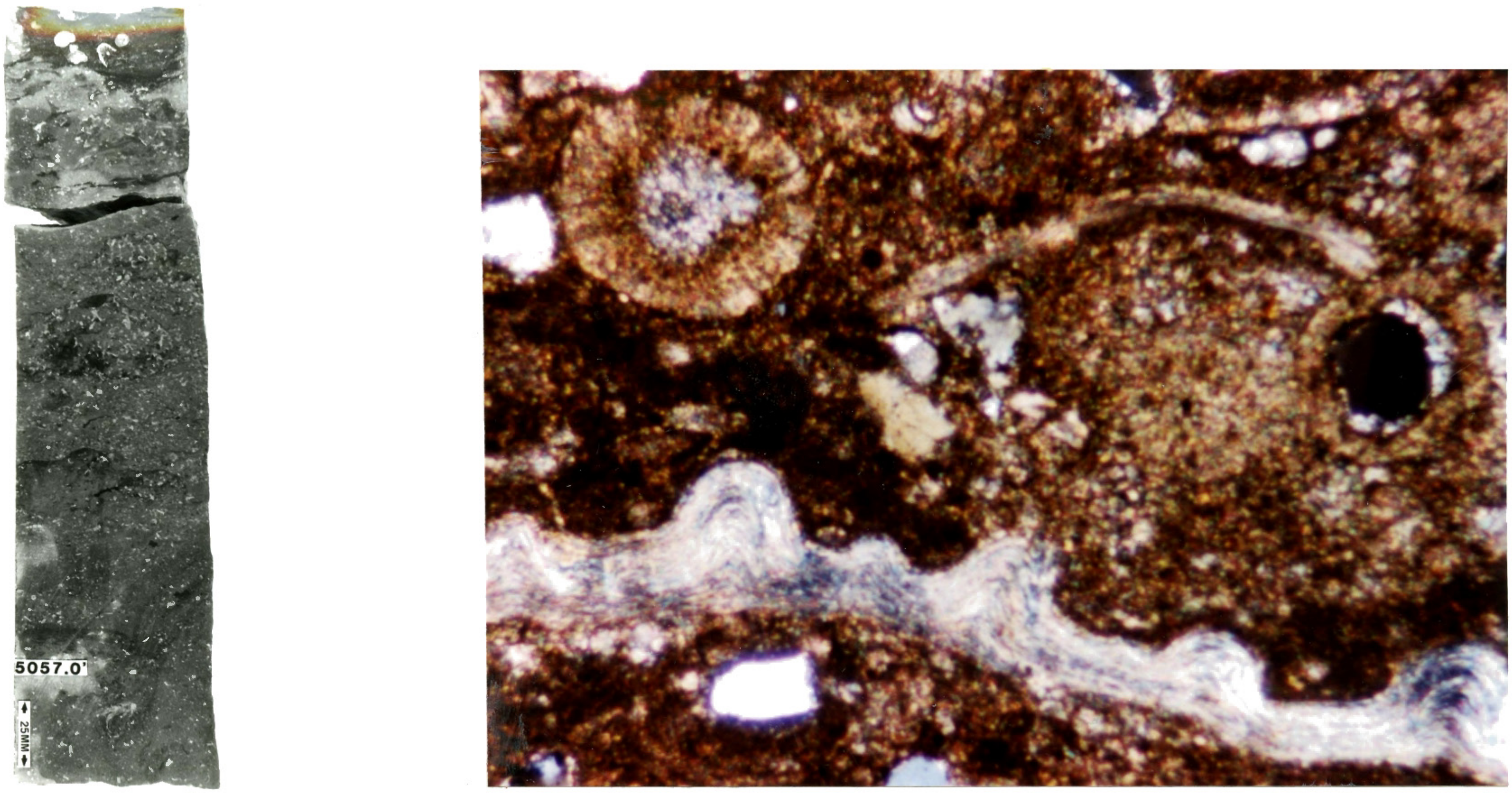


Figure 30. Photograph of Earlsboro Oil & Gas Corp., Curtis-Stark No. 1 Core: (A) Haskell Limestone; (B) Photomicrograph of Haskell Limestone Showing Brachiopod Shell and Other Fossil Fragments (100X).

The lower contact is uncertain, since the actual contact is missing from the core. The electric log signature for this core (Figure 27), however, indicates a rather abrupt contact. There is an erosional contact at the top of the interval marking the beginning of a regressive phase and the lower part of another format interval.

The gamma ray curve for this well shows a high radioactivity count from just above the Avant Limestone at 5416' to about 5310', where the response gradually shifts to the left, indicating a decreasing amount of radioactivity in the rock (Figure 23). This suggests an increase in sediment grain size from clay to silty clay or silts. At about 5215', the signature develops into a serrated funnel-shaped curve to 5116'. Above this depth, the curve becomes more subdued up to 5085', where another serrated funnel-shaped curve develops. This, in turn, is topped off with the Haskell limestone capping the format.

The signature of this format suggests a prograded deltaic sequence beginning with the distal deltaic sediments being deposited over prodelta muds at 5310'. At 5206', a distributary mouth bar developed until the channel was abandoned, prompting the development of an interdistributary bay (5110'). Near the top of the interval, transgressive limey sandstones and limestone were deposited onto the bay-fill sediment.

The intervals in the core can be broken down into the following facies: interval 1 - interdistributary bay;

intervals 2, 3, & 5 - bay-fill; interval 4 - crevasse splay within bay-fill environment; and interval 6 - marine transgression.

Shell Oil Company, Waits No. 1

This well is located just west of the study area in the Lovedale Field, Harper County (12-T26N-R20W). It was completed in June, 1960 to a depth of 6450 feet. No drill stem tests were performed on the Tonkawa interval. When originally extracted, there was 60 feet of core recovered (5100-5160'), however, only the upper 57 feet now remain. The core has not been kept in very good care. As a result, the many sections had to be pieced together before analysis could begin. Three distinct intervals can be delineated in this core (Figures 31, 32, and 33).

Interval 1 comprises the lower 20.6 feet (5136.4-5157') of strata. Most of the rock in this section is a gray, very fine-grained sandstone. However, there is a zone between 5148.8' and 5151' that consists of variegated gray, laminated sandstone and siltstone. Wavy shale laminations and occasional flasers are present in the sandstone. Clay clasts are also found at 5154'. Diagenetic siderite banding is found in several areas in this interval, giving the rock a variegated red-brown appearance. Trough cross-bedding is prevalent throughout, although much of it is obscured by the abundant load and flowage deformation features present (Figure 34). Occasional flame structures are also found in

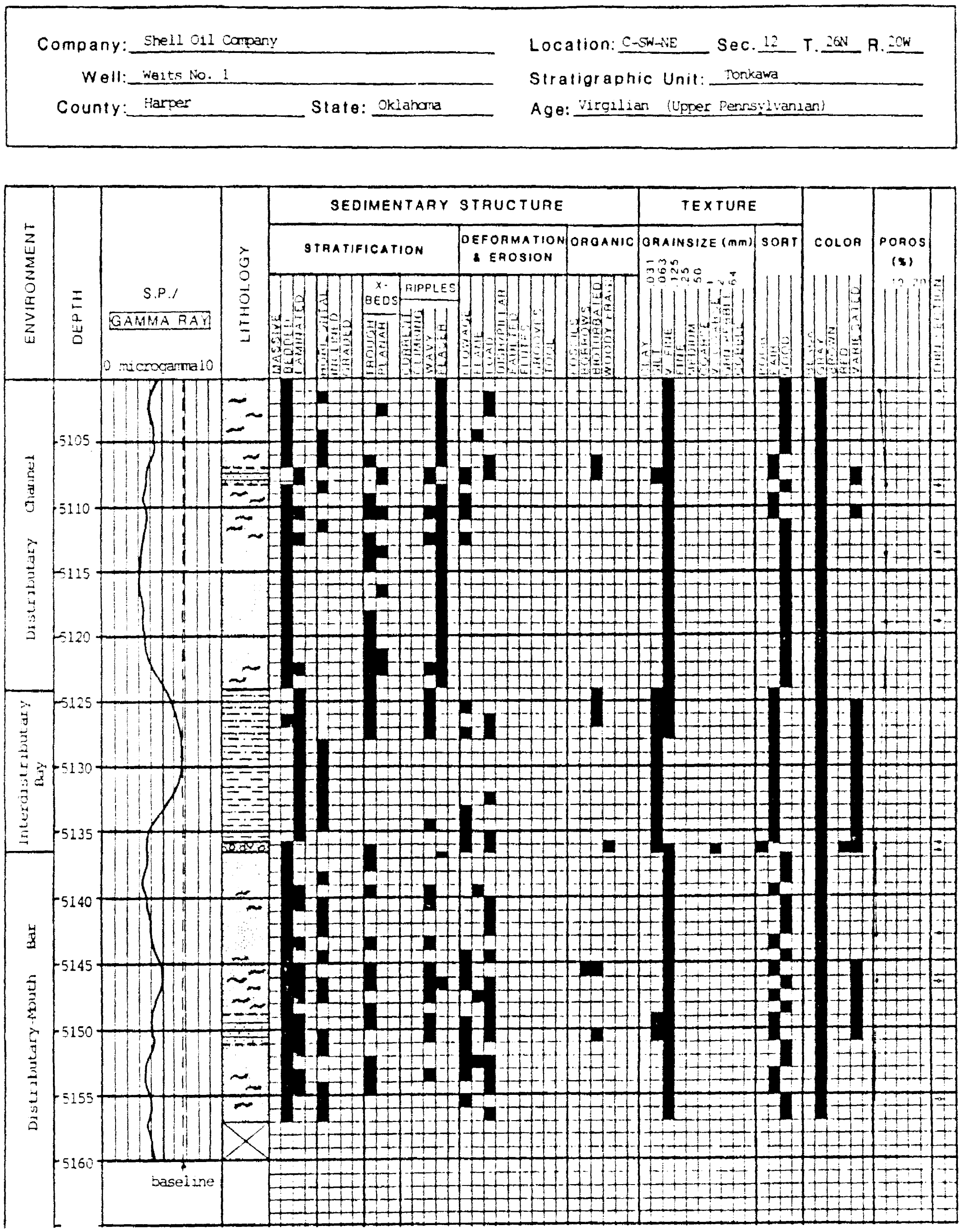


Figure 31. Log of Shell Oil Co., Waits No. 1 Core.

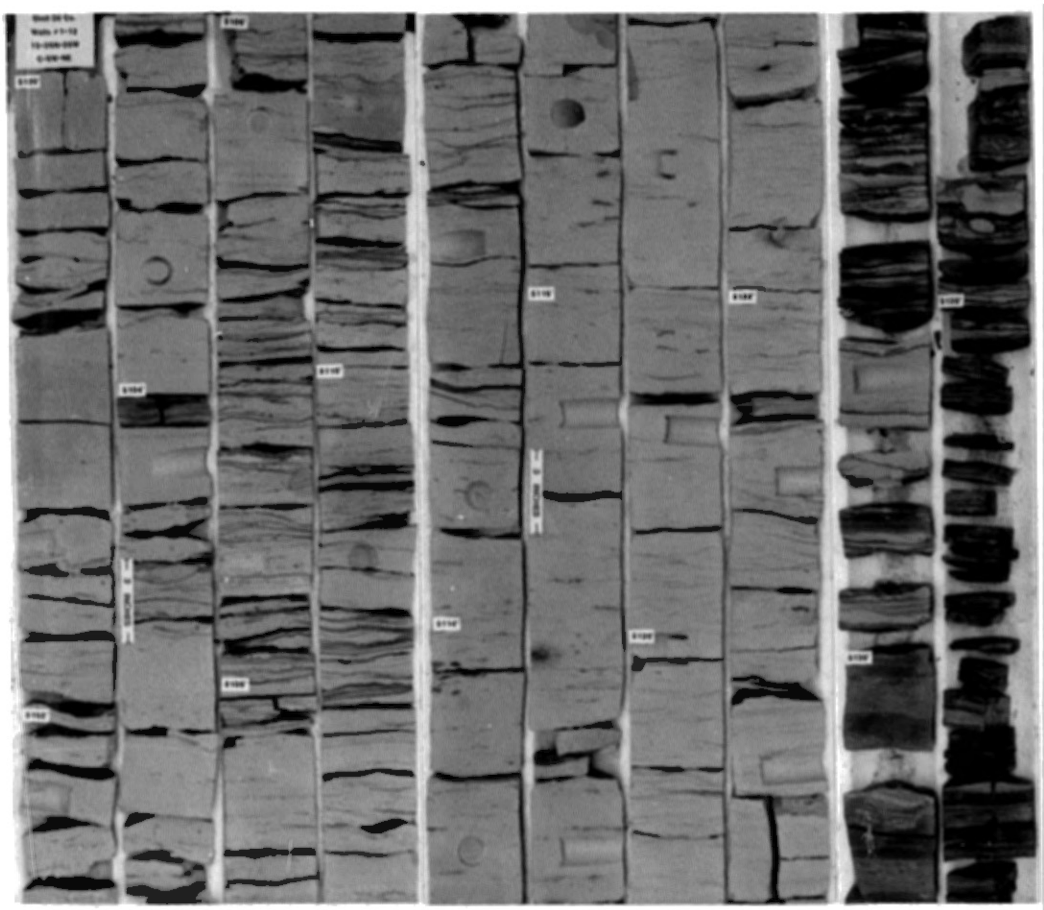


Figure 32. Photograph of Shell Oil Co., Waits No. 1 Core (Upper Portion).

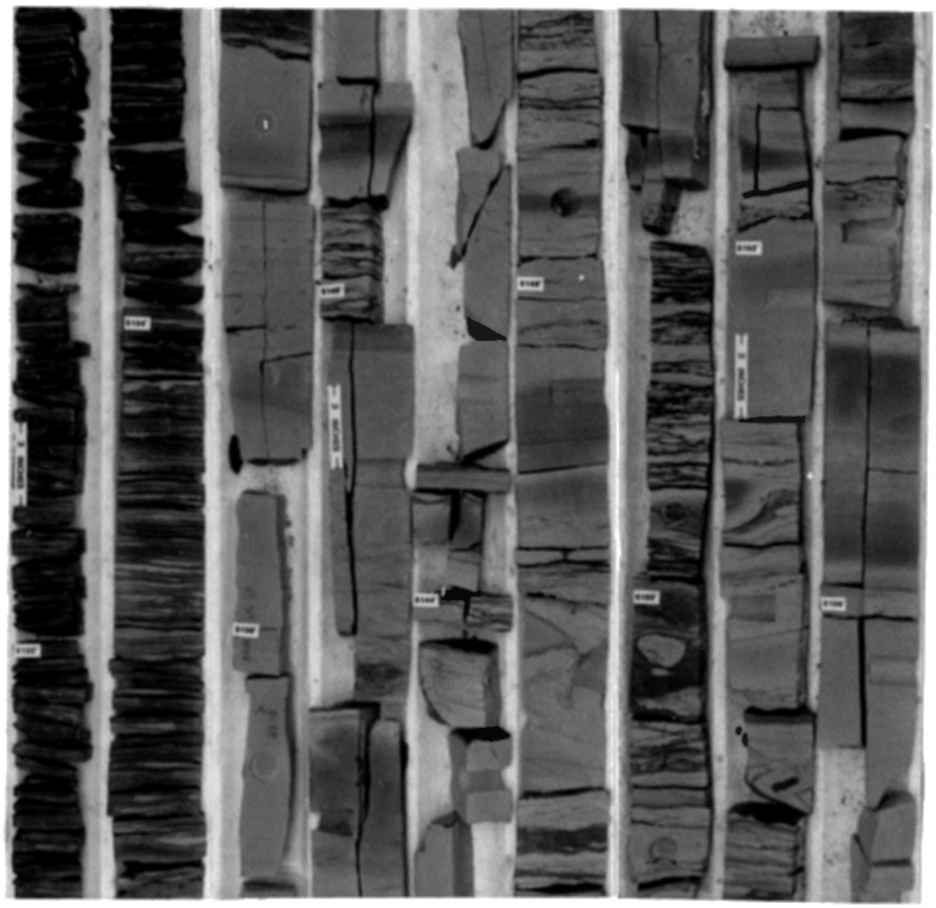


Figure 33. Photograph of Shell Oil Co., Waits No. 1 Core (Lower Portion).

(A) (B)

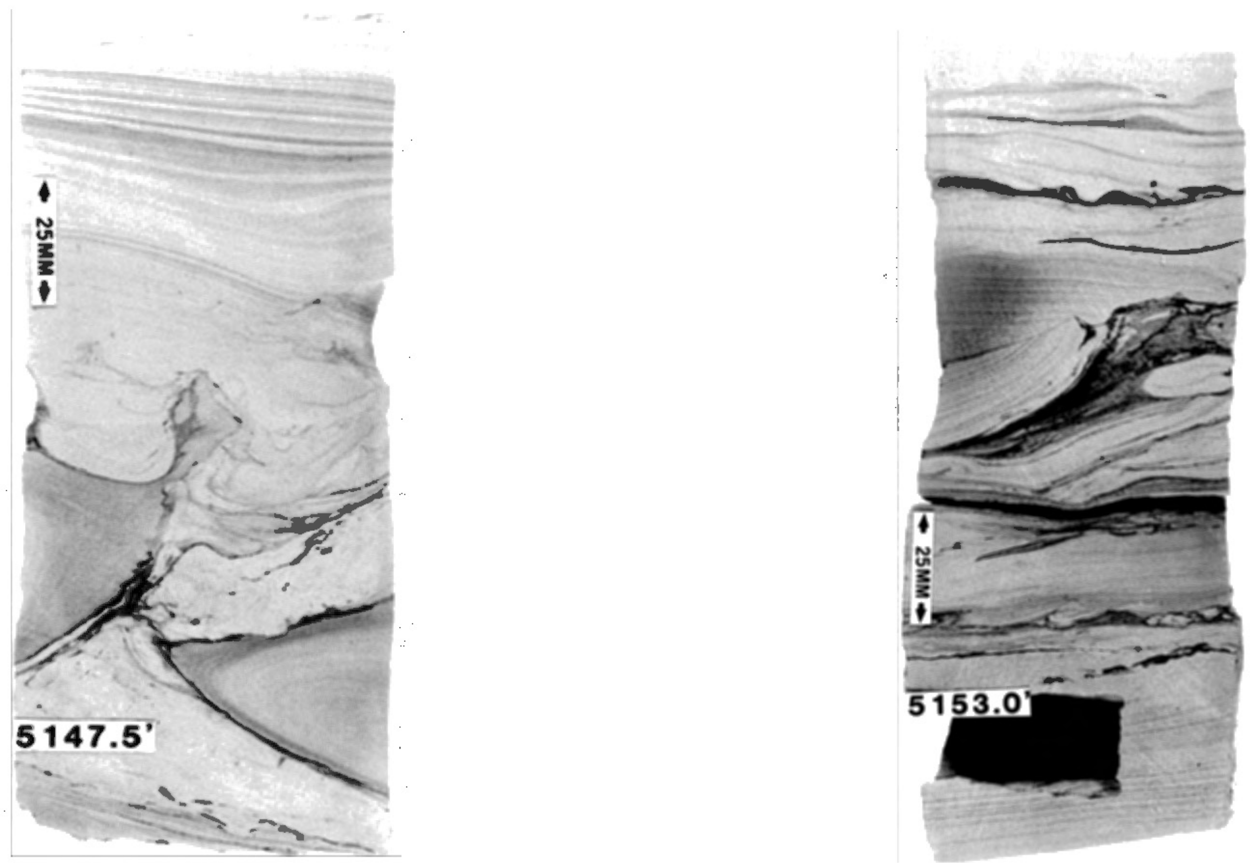


Figure 34. Photograph of Shell Oil Co., Waits No. 1 Core: (A) Load Deformation; (B) Small Scale Trough Cross Bedding, Ripples, and Flame Structures.

this section. The laminated zone mentioned above contains load deformation structures and is bioturbated.

Abrupt contacts separate interval 2 (5124-5136.4') from the intervals above and below. This section contains 12.4 feet of predominantly laminated sandy shale, with thin sandstone beds and interlaminated sandstone and siltstone. A 0.5 foot zone at the base of the interval contains interbedded very fine-grained sandstone and conglomerate (Figure 35A). The conglomeratic clay clasts have been replaced by siderite. Petrographic data shows many of these clasts to contain shell fragments. Carbonized wood were noted near the top of this zone (Figure 35B).

The laminae in the interval are mainly horizontal, changing to wavy laminations in the uppermost 4 feet of section. Sand content increases with time, resulting in an coarsening upwards sequence for this interval. Trough cross-bedding is also restricted to the upper 4 feet.

Flowage and load deformation features are present in the upper and lower parts of the section. Bioturbation is present only in the upper 3 feet.

A gray very fine-grained sandstone makes up Interval 3. This 24 feet of core (5100-5124') is mostly horizontally bedded and contains shale flasers throughout. Occasional shale laminae are also found. Pyrite is also contained in the sandstone.

A zone of wavy interlaminated sandstone and siltstone is present at 5107-5108.3'. Contained within this zone are

(A) (B)

Figure 35. Photograph of Shell Oil Co., Waits No. 1 Core: (A) Interbedded Sandstone and Conglomerate Overlying Massive Sandstone; (B) Carbonaceous Wood Fragment From Top of Conglomerate.

minor deformation structures and bioturbation features.

Trough and planar cross-bedding is present in this interval. The trough cross-bedding increases with depth while the planar decreases, indicating an increase in energy with time.

Flowage, load, and flame structures are present, although not in any great abundance. Bioturbation was found at only one location in this interval (5104').

The gamma-ray curve for this well a signature commonly found in association with delta buildup (Figure 23). There is an overall coarsening upward in the interval. Based on this and on the data discussed above, the three intervals in this core could very likely be representative of an advancing delta sequence, with interval 1 representing a distributary-mouth bar, interval 2 an interdistributary bay environment, and interval 3 a distributary channel.

Southland Royalty Company,
L. Crawford No. 1

This well is located about 20 miles to the west of the study area, near the Southwest Beaver Field in Harper County (34-T27N-R23W). It was drilled to a depth of 5365 feet. It is not known if any drill stem tests were performed on the Tonkawa in this well. The cored interval ranges from 5267' to 5315 and consists of 48 feet of various interbedded and interlaminated sandstones and shales (Figures 36 and 37).

Five separate intervals have been delineated. The

Company: Southland Royalty
Location: E-NW-NW Sec. 34 T. 27N R. 23W
Well: L. Crawford No. 1
Stratigraphic Unit: Tonkawa
County: Harper State: Oklahoma
Age: Virgilian (Upper Pennsylvanian)

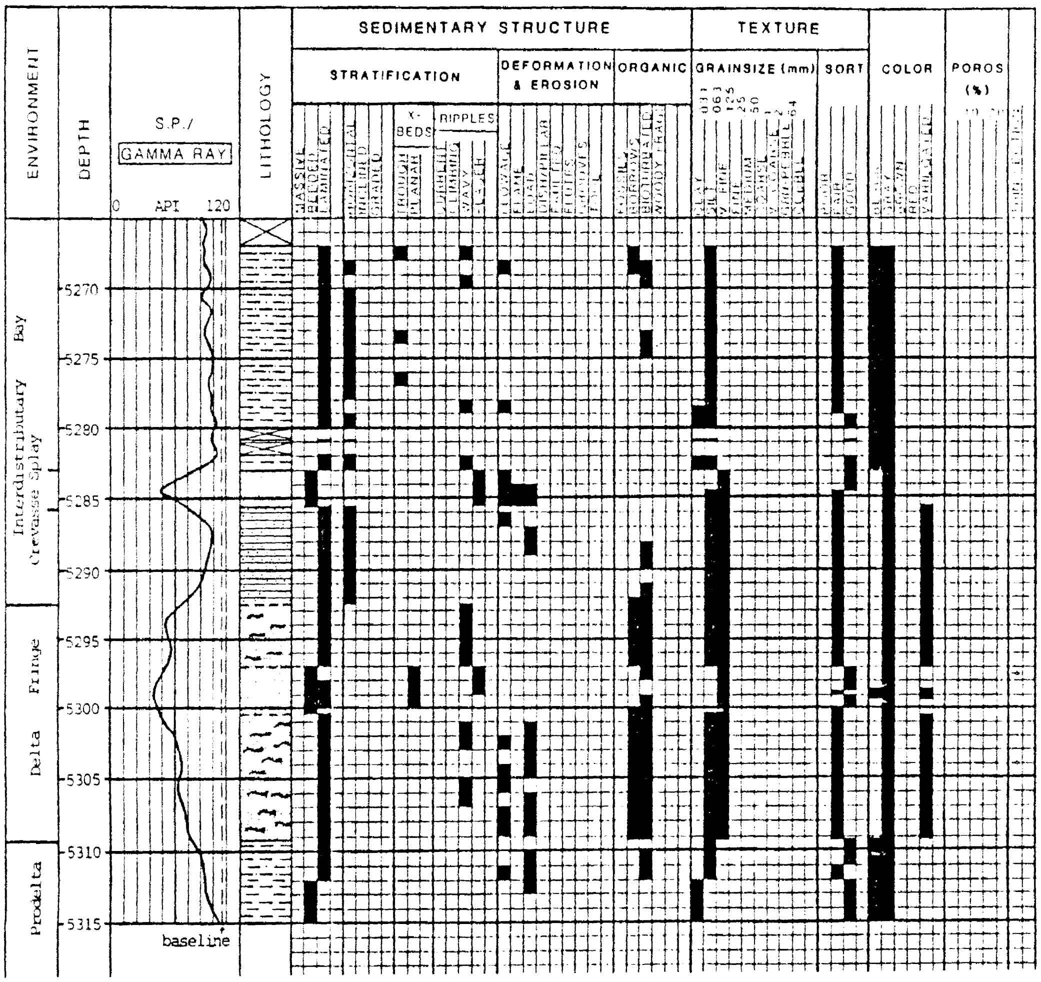


Figure 36. Log of Southland Royalty Co., L. Crawford No. 1 Core.

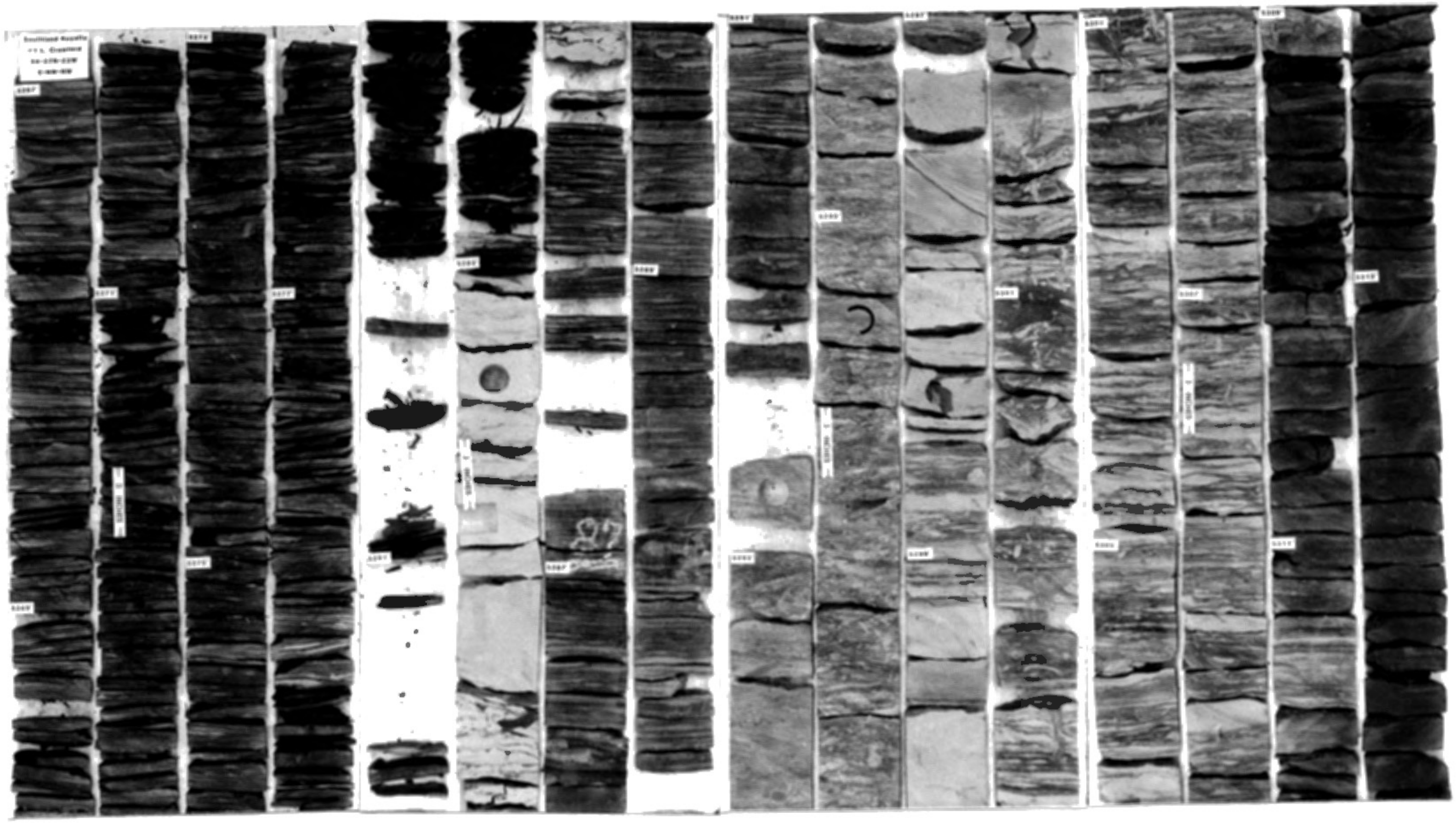


Figure 37. Photograph of Southland Royalty Co., L. Crawford No. 1 Core.

lower 5.8 foot section of strata makes up interval 1 (5309.2-5315'). This rock is a dark gray, silty shale with some thin sandstone laminations in the upper 3 feet. There is a sandstone and siltstone laminated zone between 5311-5312'. Within this zone are a few flowage and deformation structures. Bioturbation features in the interval are restricted to this zone as well. Sand content increases upward in section to the upper sharp contact with the overlying interval.

Interval 2 is a 17 foot section of rock (5292.2-5309.2') composed of variegated gray, sandstone with abundant siltstone interlaminations. A zone, 3.4 feet thick, of a highly oolitic, very fine-grained sandstone is present in the upper part of the section (5297-5300.4) (Figure 38A). Shale laminae are seen in the middle part of this zone. This interval exhibits pronounced bioturbation and borrowing structures, indicative of intense organic activity (Figure 38B). In fact, the abundance is so great as to practically obscure many of the stratification and deformation features present. Careful observation shows that the siltstone laminations are horizontal to wavy. Load and flowage deformation features are present below 5301'. Siderite is also present in isolated areas in this section.

A gradational contact marks the lower boundary of interval 3. This interval is a 7 foot section of strata (5285.6-5292.2') containing variegated gray, siltstone and very fine-grained sandstone. The laminations are

(A)

(B)

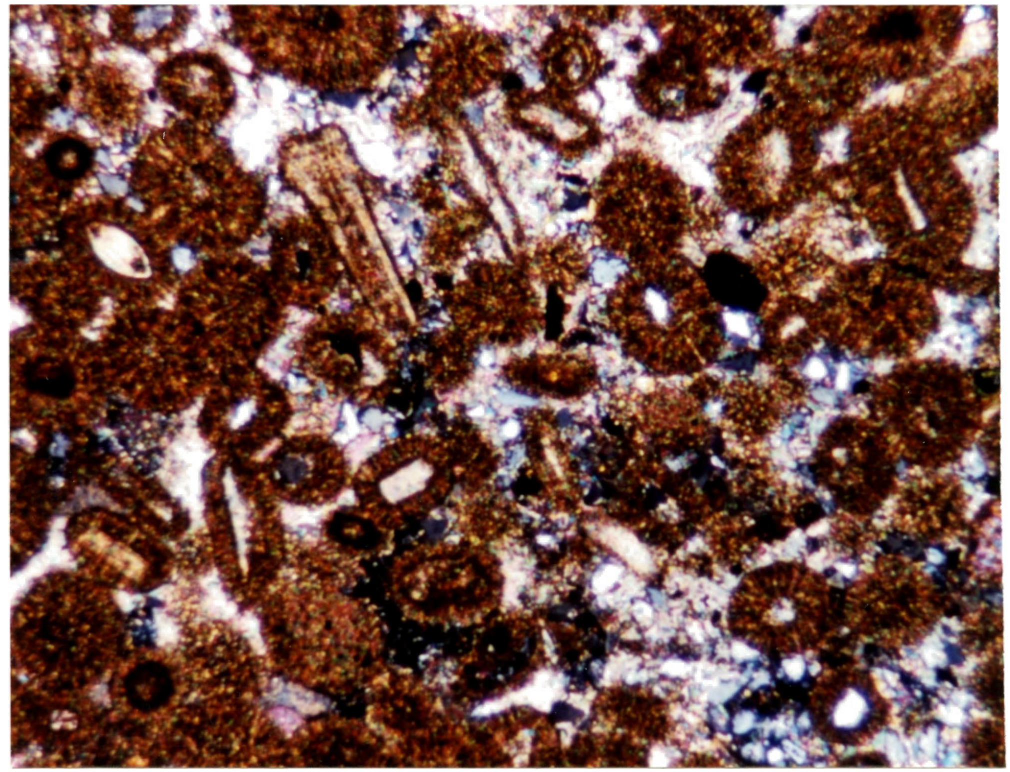


Figure 38. Photograph of Southland Royalty Co., L. Crawford No.1 Core: (A) Photomicrograph of Oolitic Sandstone (100X); (B) Bioturbation and Load Structures.

predominantly horizontal, although minor wavy laminae can be found. Minor flowage and load deformation are located near the top of the interval. Bioturbation features are present in the lower two-thirds of the section.

Interval 4 is a 2.6 foot section of strata bounded by sharp contacts (5283-5285.6'). This gray, very fine-grained sandstone contains small shale flasers scattered sporadically throughout, as well as some wavy shale laminae. These laminae are restricted to the basal part of the interval. Also present in the lower part of the section are clay clasts that have been replaced by siderite. Flowage, flame, and load deformation structures are present in minor amounts. No burrowing was detected.

The uppermost section, interval 5, contains 16 feet of variegated gray, laminated sandy shale (5267-5283'). Most of the laminae are horizontal, however, there are some that are inclined at very low angles. The sand to shale lamination ratio increases upward making, the interval a coarsening upward sequence.

Minor flowage features are present in a couple of locations. Bioturbation structures are found throughout the section. Distinct burrows are seen in the upper portions of the interval.

The gamma ray curve signature and core data suggest that the Tonkawa format in this well also represents a deltaic type of environment. The gamma ray curve was used in lieu of the sp-curve because of the lack of development of the sp-curve. It shows a funnel type character for the lower part of the core, corresponding to intervals 1 & 2 discussed above. These two intervals can be interpretated as prodelta and distal delta front facies, respectively. The higher gamma ray reading above this funnel shaped signature matches interval 3, indicative of an interdistributary bay environment. Interval 4 coincides with a decreased gamma ray reading indicating increased grainsize. This interval probably represents a crevasse splay or a short-lived distributary channel facies. Above this, the curve gives a shaly reading, corresponding to interval 5. This would most likely be an interdistributary bay-fill facies.

CHAPTER VIII

PETROLOGY AND DIAGENESIS OF THE TONKAWA SANDS

Introduction

The analysis of the sandstones was performed utilizing thirty-four thin sections. Twenty-nine of these were used to determine the detrital components of the sands. The other five, including the two from the Southland Royalty, L. Crawford No. 1 core, were too diagenetically altered to yield accurate determinations. X-ray diffractions of 20 bulk samples and 6 clay extractions were run in order to assist in identifying constituents.

Detrital Constituents

The Tonkawa sandstones are very fine- to fine-grained, subrounded to rounded, and have moderate sphericity. They also display moderate to good sorting. Percentage data from the twenty-nine samples used for this section were plotted on a Q-R-F diagram (Figure 39). These all plot as sublitharenites. Variations were minor, most likely reflecting deposition in different environmental facies.

The major constituents present are quartz, rock fragments, feldspars, and muscovite. Chlorite matrix was

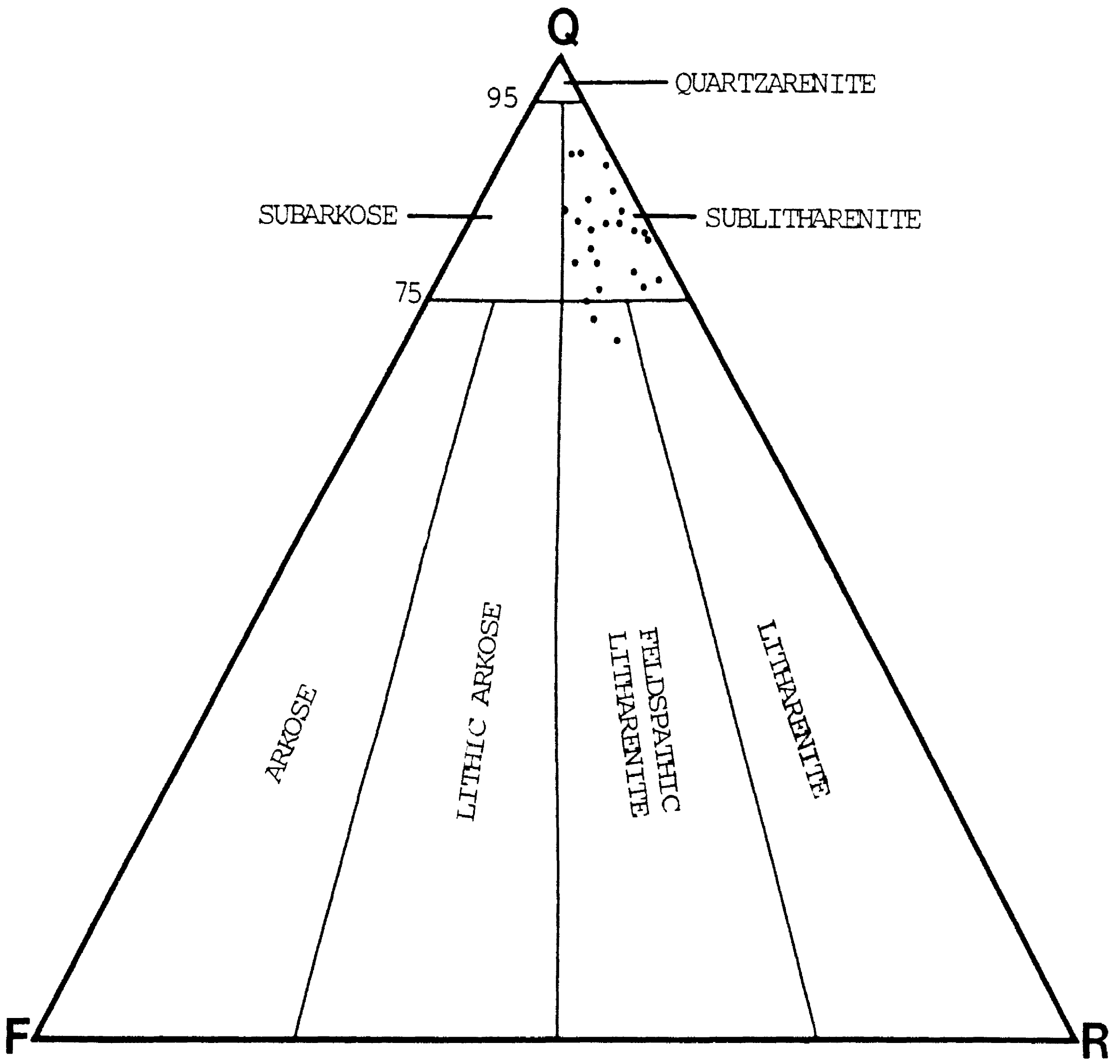


Figure 39. Classification of Tonkawa Sandstones.

also present in appreciable amounts in the sands in two of the cores. Table I lists all of the detrital constituents and percentages of each found in the cores.

Monocrystalline quartz is the most abundant detrital constituent in the sandstones. Some grains display undulose extinction. The edges of a few grains are slighlty corroded. All of the thin sections contain polycrystalline grains but in low abundance (Figure 40). These grains tend to be slighlty to moderately corroded. Many exhibit dissolution to some degree.

The rock fragments consist of both metamorphic and sedimentary types (Figure 40). Phyllite and schist clasts make up the metamorphic component. The sedimentary component is made up of illitic mudstone, which is commonly seen as rip-up clasts from flasers and stringers. Some of these clasts are organic rich. Metamorphic grains tend to show diagenetic alteration, whereas the sedimentary fragments commonly display deformation due to compaction.

Orthoclase makes up the bulk of the feldspar component, and usually shows moderate to high alteration. This gives the grains a cloudy appearance. Albite plagioclase is present in minor amounts (Figure 41). It also tends to be altered, although not to the degree of the orthoclase.

Muscovite is a relatively abundant accessory mineral in all but a few thin sections (Figures 42). The greatest occurrence of these grains in the vicinity of shale stringers and flasers, where they are aligned in a sub-

TABLE I

AVERAGE DETRITAL COMPOSITION OF THE TONKAWA SANDSTONE

Constituent	Core 1	Core 2	Core 3	Percentage Ave. (%)
Quartz	59.8	57.3	46.6	54.6
Rock Frags	12.3	8.9	6.0	9.1
Feldspars	1.3	4.7	3.6	3.2
Muscovite	2.3	2.6	4.6	3.2
Chlorite Matrx	tr	4.3	0.8	1.7
Chlorite	tr	tr	tr	tr
Biotite	tr	--	tr	tr
Glauconite	tr	tr	tr	tr
Organic Matter	tr	--	tr	tr
Chert	tr	tr	tr	tr
Tourmaline	tr	tr	tr	tr
Zircon	tr	tr	tr	tr

Core 1: Gulf Oil Co., Shade No. 1
Core 2: Earlsboro Oil & Gas, Curtis-Stark No. 1
Core 3: Shell Oil Co., Waits No. 1

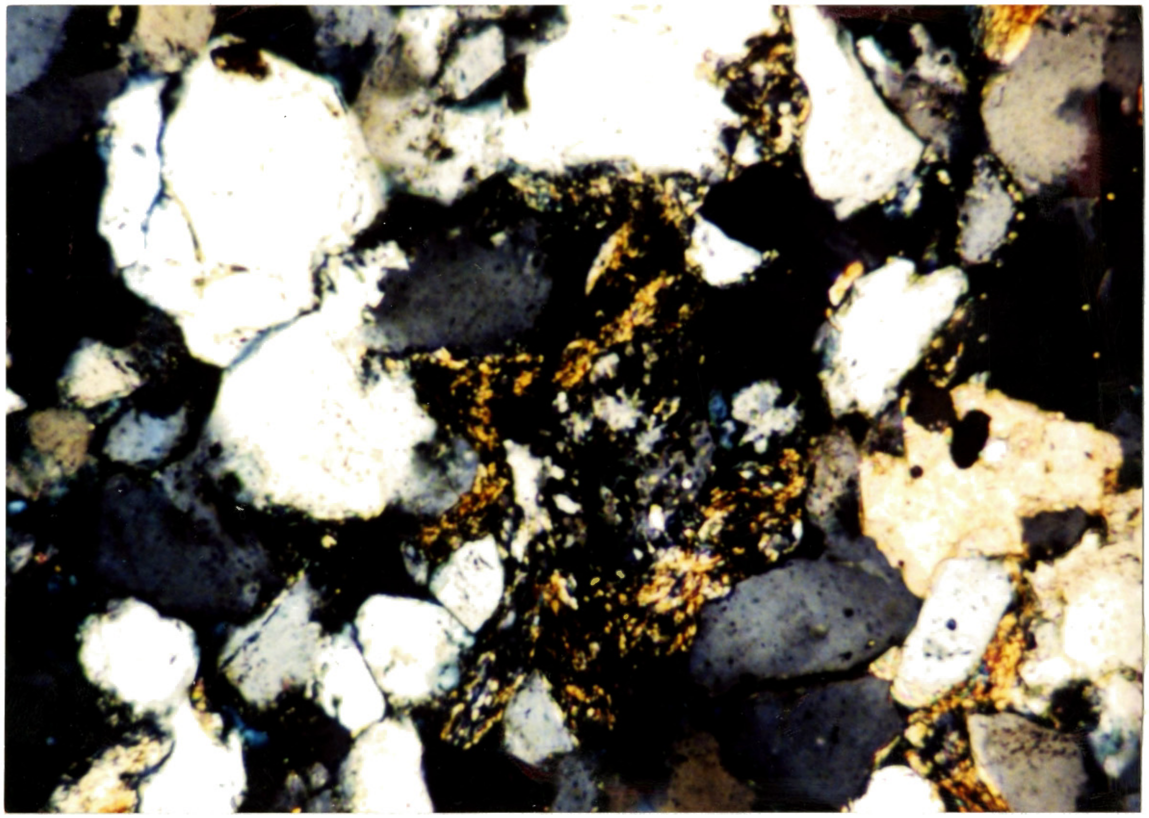


Figure 40. Photomicrograph of a Deformed Sedimentary Rock Fragment and Metamorphic Rock Fragment Along Upper and Lower Edge Polycrystalline of Grain; Quartz Overgrowths; and Carbonate Pore Filler (Gulf Oil Corp., Shade No.1, 100X, XN).

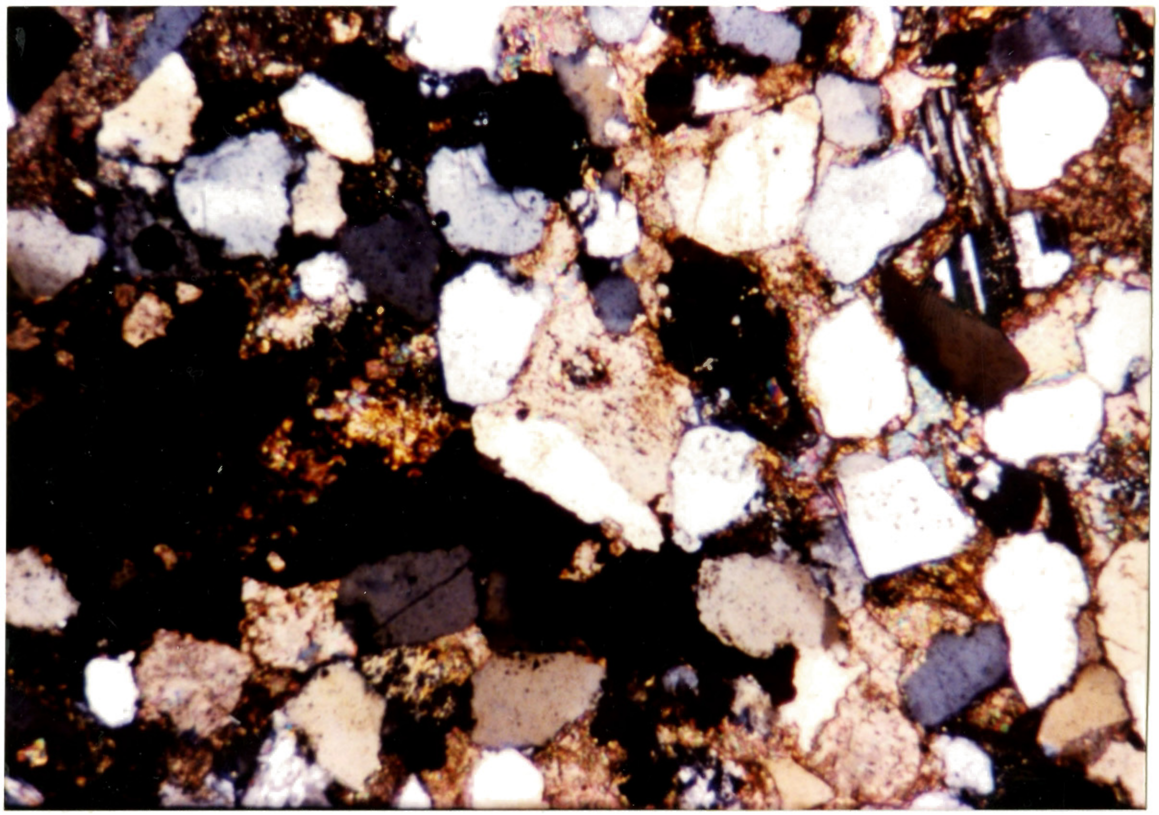


Figure 41. Photomicrograph of Calcite Pore Filling Cement; Residual Oil Filling Pores on Left Side of Photo; Chlorite Rims Around Grains, and Albite Plagioclase (Shell Oil Co., Waits No. 1, 100X, XN).

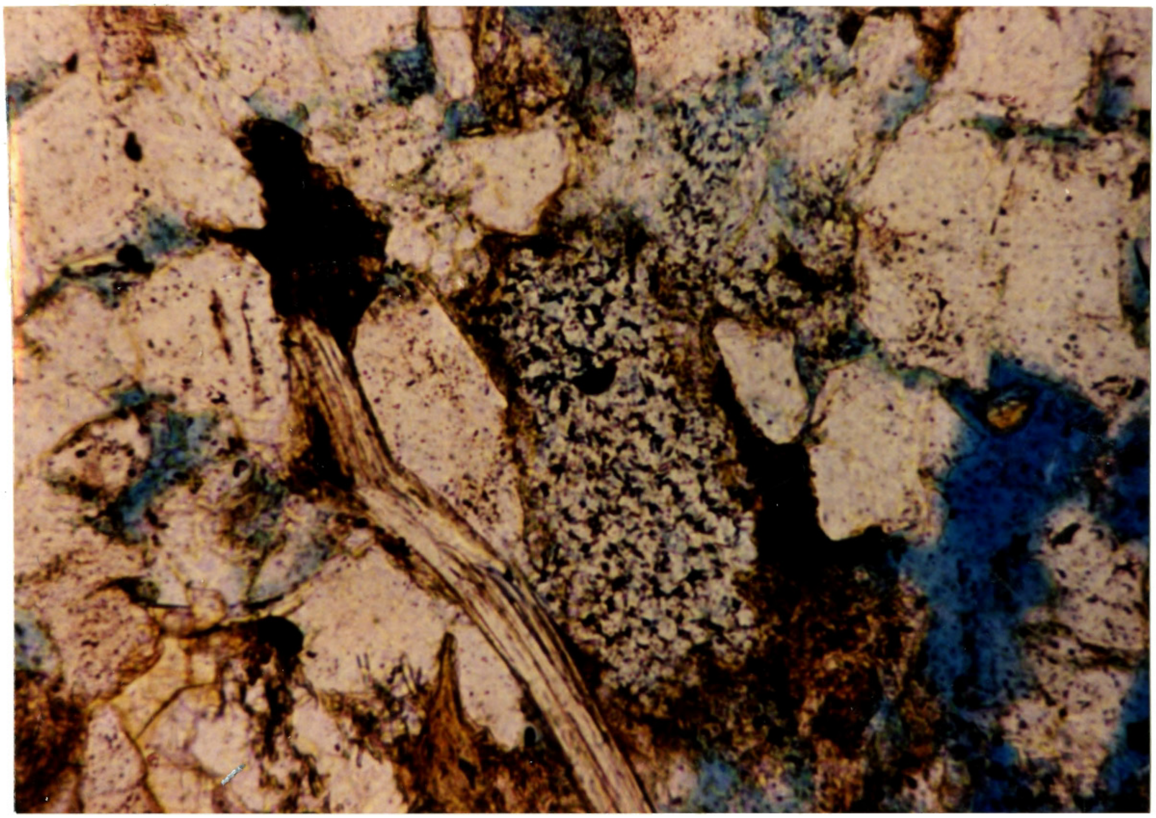


Figure 42. Photomicrograph of Bent Muscovite Grain; Kaolinite Replacing a Feldspar Grain, Which is Itself Being Replaced by Pyrite; and Secondary Porosity (Gulf Oil Corp., Shade No.1, 100X, PPL).

horizontal manner. Many grains are also bent, indicating compaction after burial.

Detrital matrix is made up of predominantly chlorite, much of which was removed or replaced subsequent to burial. Nevertheless, some can be rimming quartz grains as well as filling pore spaces. Trace amounts of illite are also present, however, this material is much more common to shale stringers and flasers.

Accessory minerals accounting for trace amounts of the detrital constituents present include biotite, chlorite, chert, glauconite (Figure 43), organics, tourmaline, and zircon. Most of the organics are associated with the mudstone flasers and stringers, however, there are occurrences of organics in the form of residual oil that fills pores in some locations (Figure 41 and 44).

Authigenic Constituents

A list of the authigenic constituents present in the sandstones, and the average percentage of each, is shown in Table II. Calcite is the main diagenetic product. It usually occurs as poikilotopic masses and acts as the major pore filler in the sands (Figure 41). Associated with the calcite is siderite, the second most abundant constituent. This cement usually appears as reddish masses of rhombic crystals in pore spaces (Figure 45). Silica cement is the third most abundant diagenetic constituent. It appears to have formed early as quartz overgrowths (Figure 40 and 44).

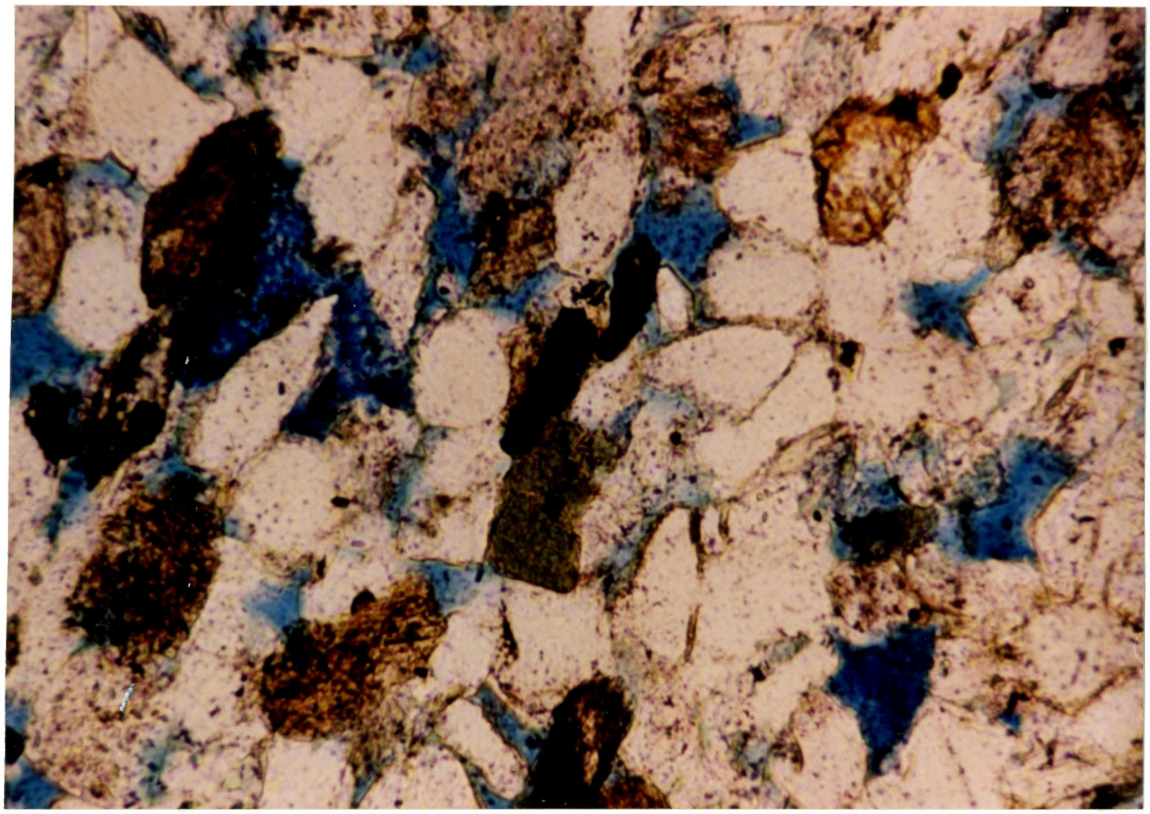


Figure 43. Photomicrograph of Detrital Glauconite Fragment; Kaolinite in Upper Left of Photo; and Secondary Porosity (Gulf Oil Corp., Shade No.1, 100X, PPL).

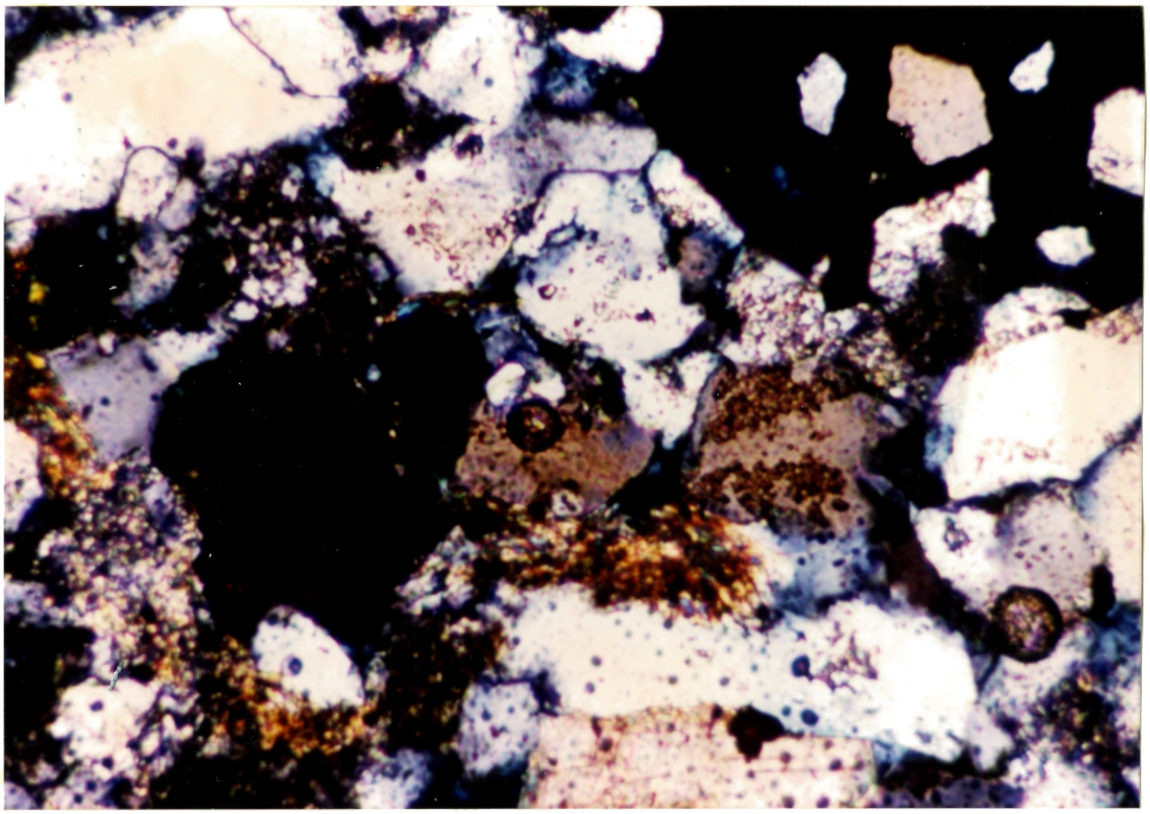


Figure 44. Photomicrograph of Quartz Overgrowths Filling Pores; Residual Oil in Upper Right of Photo; Deformed Sedimentary Fragment; and Secondary Porosity (Earlsboro Oil & Gas, Curtis-Stark No. 1, 100X, XN).

TABLE II

AVERAGE AUTHIGENIC COMPOSITION OF
THE TONKAWA SANDSTONE

Constituent	Core 1	Core 2	Core 3	Percentage Ave. (%)
Calcite	3.5	13.1	11.6	9.4
Siderite	tr	0.5	12.0	4.2
Quartz Overgrowth	4.0	4.6	2.1	3.6
Chlorite	1.4	tr	0.9	0.8
Pyrite	1.1*	tr	0.8	0.6
Kaolinite	0.7	0.5	tr	0.4
Illite	tr	tr	--	tr

* Originally residual oil that has been replaced by pyrite.

Core 1: Gulf Oil Co., Shade No. 1
Core 2: Earlsboro Oil & Gas, Curtis-Stark No. 1
Core 3: Shell Oil Co., Waits No. 1

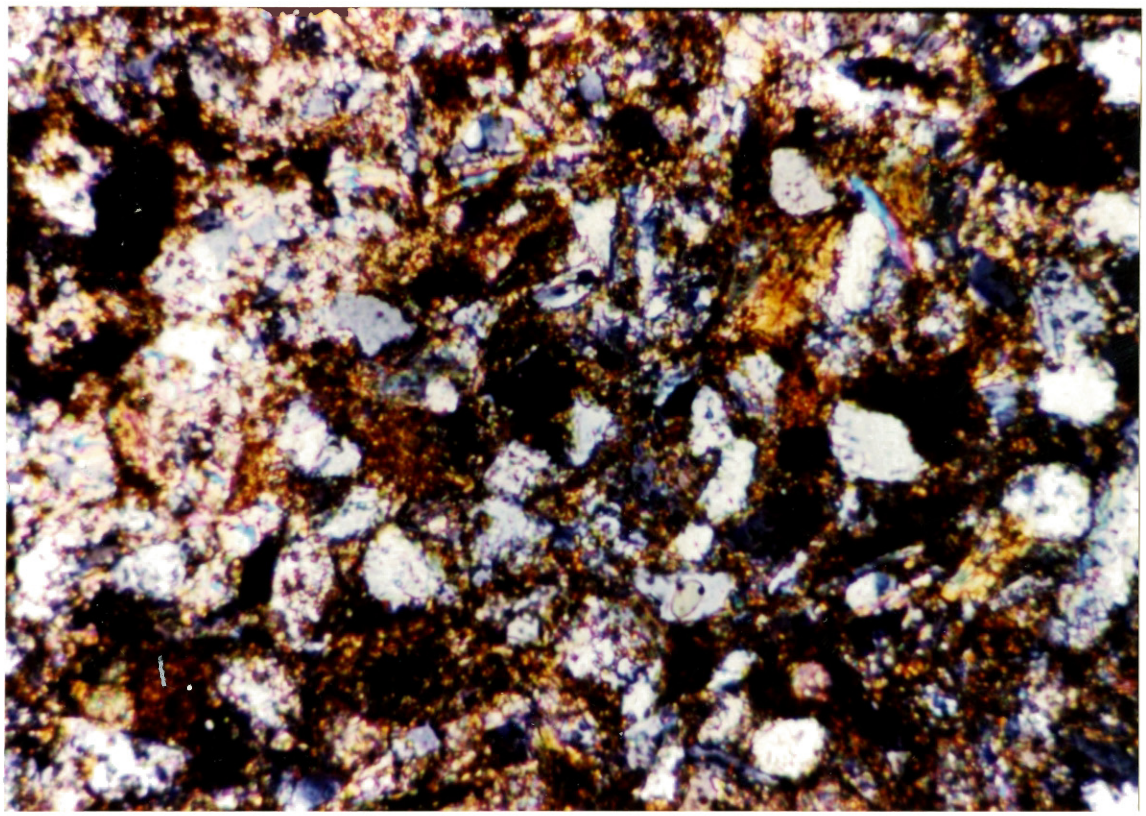


Figure 45. Photomicrograph of Siderite Filling Pore Spaces (Southland Royalty, L. Crawford No. 1, 100X, XN).

The authigenic clays present in the cores are chlorite, kaolinite, and illite. Chlorite is the most abundant clay, present mainly as pore-liners, also occurs rimming grains (Figure 41). Kaolinite is present as a pore-filling clay. It also acts as a diagenetic replacement for detrital grains such as orthoclase (Figure 42). The occurrence of illite is very minor and was recrystallized from detrital mudstone fragments (Figure 40 and 44).

Pyrite is present in all samples and is relatively abundant in several thin sections. Although some pyrite-replacing kaolinite does occur (Figure 42), most is seen in association with organic matter. Anaerobic conditions caused the formation of pyrite from this organic matter instead of giving rise to hematite and other minerals associated with oxidizing environments.

Porosity

There is substantial variation in the average porosities of the sandstones in the different cores. Table III shows the ranges and average percent porosities for the four wells. These values are thought to be representative of sands in the cored interval as determined from thin section analysis. The sands of the Gulf Oil Corp., Shade No. 1 well show the highest porosity values. The values for the other three wells are substantially lower. Presence of carbonate as pore-filling cement is the main reason for this and could be related to the environments where the sands

TABLE III

POROSITY RANGES AND AVERAGES
FOR THE CORES STUDIED

Well	Maximum (%)	Minimum (%)	Average (%)
Gulf Oil Corp., #1 Shade	14.0	9.0	11.5
Earlsboro Oil & Gas, #1 Curtis-Stark	4.0	<0.3	1.9
Shell Oil Co., #1 Waits	5.0	<0.1	2.0
Southland Royalty, #1 L. Crawford	<0.1	0.0	<0.1

were deposited.

The porosity is almost wholly secondary, with only trace amounts of primary types. Reduced intergranular porosity is evidenced from the precipitation of quartz overgrowths, carbonates, and pyrite. Secondary porosity types present include, in decreasing abundance, enlarged, moldic, and microporosity (Figure 42, 43, and 44).

Elongate (enlarged) pores developed mainly from the partial dissolution of detrital matrix and authigenic carbonate cements. Moldic porosity results from dissolution of detrital grains, namely feldspar grains and rock fragments, and to a lesser extent, quartz grains. Microporosity typically develops between individual clay booklets of kaolinite and is, therefore, directly proportional to the amount of kaolinite in the rock.

Paragenesis

A paragenetic sequence was developed during analysis of the thin sections. Figure 46 is a graphical representation of this sequence.

Silica cement appears to have been the first diagenetic constituent to precipitate in the Tonkawa sandstones analyzed. Primary porosity values must have been relatively high to allow for the transportation of silica-rich pore fluids through the rock. This is an indication that little detrital matrix was present in the sediment when deposited. The formation of quartz overgrowths is hindered in some

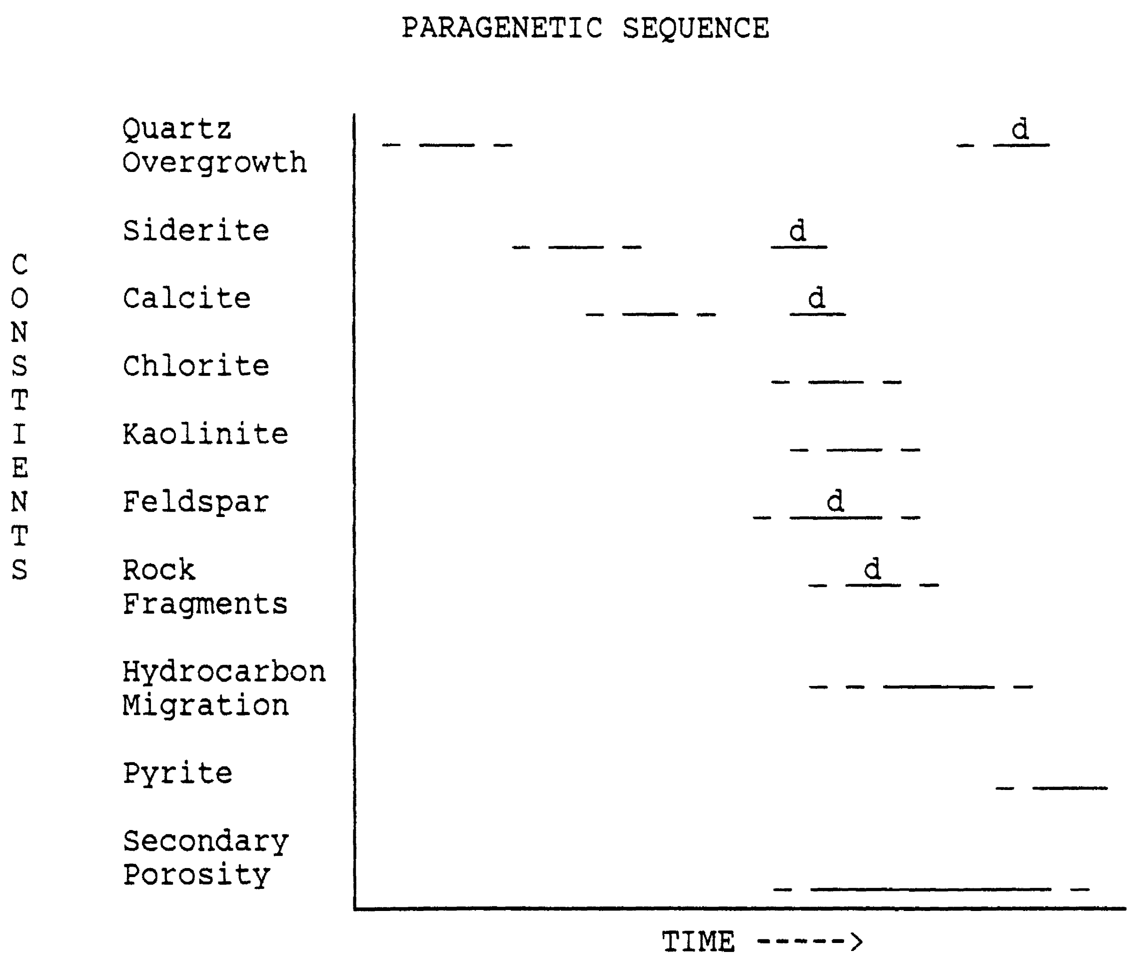


Figure 46. Paragenetic Sequence for Tonkawa Sandstones.

areas due to the rimming of quartz grains by chlorite. This chlorite is probably detrital matrix that was recrystallized during early diagenesis.

The precipitation of siderite occurred during the next diagenetic phase, indicating a lowering of Eh and increased carbonate activity. Siderite usually forms in iron-rich sediments where there is a high carbon dioxide (CO_2) and methane (CH_4) content. Such quantities of these gases are typically associated with deltaic environments. In addition, siderite is precipitated during early diagenesis at shallow burial depths.

Most of the siderite in the sediments is observed as pore filling rhombic crystals surrounding detrital grains. It is also associated with the mudstone rock fragments. One might infer that these clasts were iron-rich and possibly carbonaceous. Many of the clasts present in the cores have been altered to siderite.

Calcite was precipitated during the waning stages of siderite precipitation. It is present as poikilotopic masses filling pore spaces and pore throats, and is most prevalent in areas with little or no siderite development. In those locations where the two are seen together, the calcite appears to be replacing the siderite grains.

Dissolution of feldspars and rock fragments (especially metamorphic clasts) resulted from a buildup in the amount of carbonic acid in the pore waters (Al-Shaieb & Shelton, 1981). Chlorite and kaolinite are the major alteration products of this dissolution. Carbonates which were precipitated earlier also now experience dissolution. This phase marks the initial development of secondary porosity in the sands.

The CO_2 in the carbonic acid is thought to be directly related to the generation of hydrocarbons (Al-Shaieb & Shelton, 1981), therefore, its presence usually indicates subsequent migration of these hydrocarbons. Dissolution of quartz overgrowths probably takes place concurrently with the oil migration, as evidenced by the residual oil filling void left by this dissolution.

Formation of authigenic pyrite takes place after the hydrocarbon migration. Evidence for this is the replacement of residual oil by the pyrite. Organics in the mudstone clasts have also undergone alteration to pyrite.

CHAPTER IX

PETROLEUM GEOLOGY

Introduction

The Tonkawa sandstones are predominantly gas producing rocks, although most wells do produce limited amounts of oil. Gas dissolution is the main driving mechanism for these wells. The unit is productive in 63 wells in 10 of the 43 fields present within the limits of the study area (Figure 47 and Table IV). As of January 1984, total production of gas was 129.5 BCF (Dwight's Energy Data, 1984) (Table V). Through August 1984, at least 610,638 barrels of oil have also been produced (Petroleum Information, 1984) (Table VI).

Stratigraphic pinchouts are the main trapping mechanisms for the Tonkawa sands on the Northern Shelf of the Anadarko Basin. The producing facies are usually stream-mouth bar sands. Channel deposits and crevasse splays can also serve as producing facies. Figure F-F' (Plate 1) illustrates the trapping mechanisms. Wells 3 and 6 produce gas from sands that pinch out just updip of the well location. These well are in the Northwest Avard and Northeast Waynoka fields, respectively.

The discovery well for the Tonkawa in the study area is

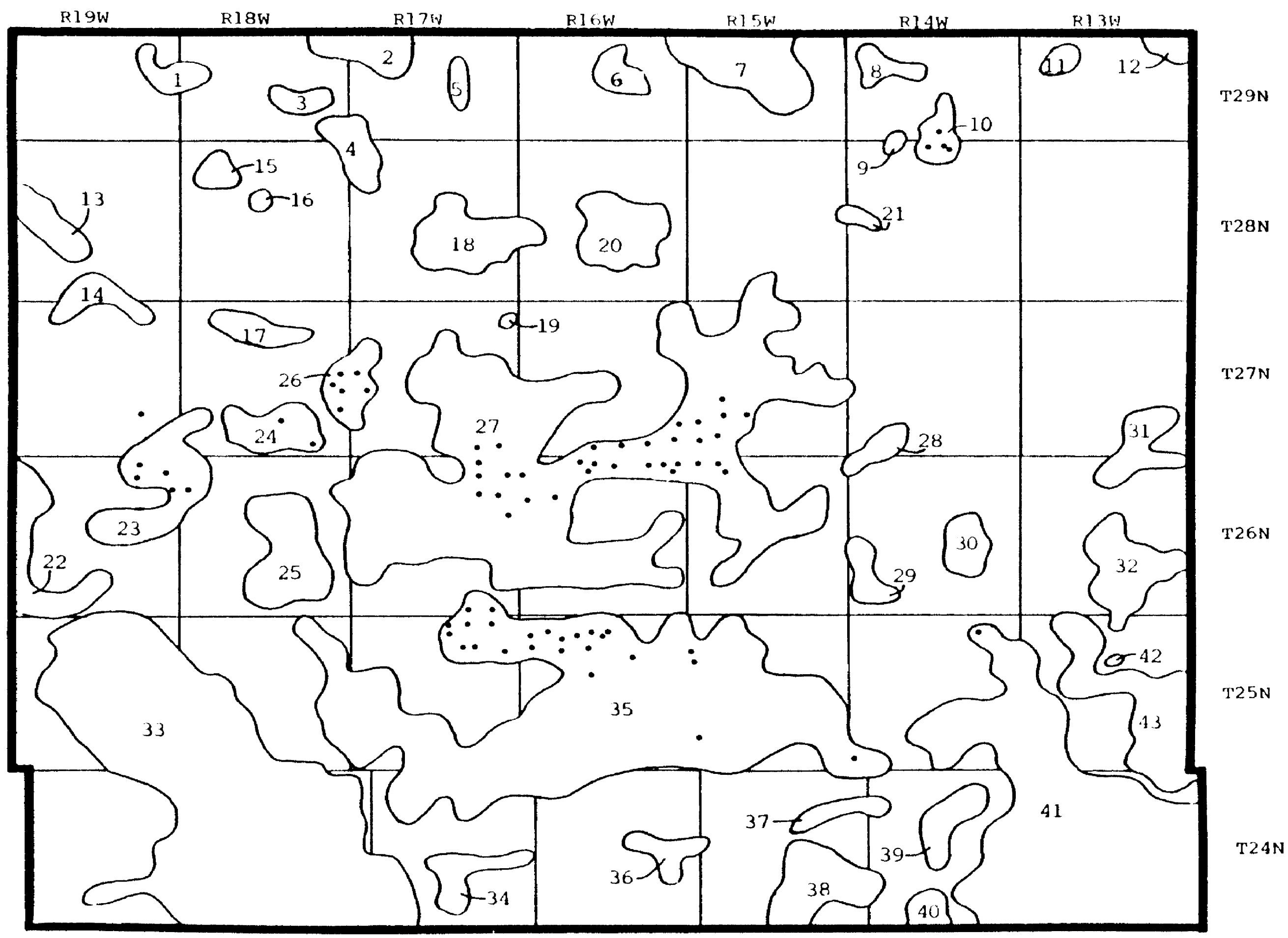


Figure 47. Locations of Oil and Gas Fields in the Study Area. (See Table IV for field names). = Undifferentiated Tonkawa production.

TABLE IV

OIL AND GAS FIELDS IN STUDY AREA

Map No.	Field Name	Map No.	Field Name
1	Lookout, Northeast	31	Alva, East
2	Yellowstone	32	Alva, Southeast
3	Yellowstone, Southwest	33	Cedardale, Northeast
4	Yellowstone, South	34	Quinlan, Northeast
5	Yellowstone, Southeast	35	Waynoka, Northeast
6	Falkner, Northeast	36	Waynoka, South
7	Wolgamoto	37	Waynoka, East
8	Winchester, Northeast	38	Waynoka, Southeast
9	Winchester, East	39	Greenburg, Southwest
10	Fritzlen	40	Cheyenne Valley
11	Capron, Northwest	41	Oakdale
12	Capron, North	42	Dacoma, West
13	Edith, Northwest	43	Dacoma, South
14	Edith, North		
15	Lookout, Southeast		
16	Farry, Northwest		
17	Farry, Southwest		
18	Farry, Northeast		
19	Whitehorse, North		
20	Falkner, Southeast		
21	Winchester, Southeast		
22	Lovedale		
23	Edith, South		
24	Freedom, Northwest		
25	Freedom, Southwest		
26	Freedom, North		
27	Avard, Northwest		
28	Noel, Southwest		
29	Avard, East		
30	Hopeton, North		

TABLE V

GAS PRODUCTION TO 12/84*

FIELD	# WELLS		YR PRD (MCF)	CUMULATIVE (MMCF)
Avard, Northwest	28		1216953	83193.8
Waynoka, Northeast	23		627420	38024.6
Fritzlen	5		870768	2944.9
Edith, South	3		82266	1904.9
Freedom, Northwest	2		8437	1447.4
Dacoma, South	1		51241	971.9
Waynoka, South	1		50501	706.7
Falkner, Southeast	0		9679	245.3
Oakdale	0		0	18.8
	63	TOTAL:	2917265	129458.3
			=2,917.265 MMCF	=129.46 BCF
			=2.92 BCF	

* Compiled from Natural Gas Well Production Histories (Dwight's Energy Data, 1984).

TABLE VI

TONKAWA OIL PRODUCTION TO 08-84*

FIELD	# WELLS	YTD (BBL)	CUMULATIVE (BBL)
Avard, Northwest	22	2571	402,404
Waynoka, Northeast	20	1166	147,915
Edith, South	2	1337	19,217
Dacoma, South	1	160	18,983
Fritzlen	2	1690	8,440
Wapanucka, Northeast	1	176	6,537
Freedom, Northwest	1	0	3,870
Waynoka, South	1	113	3,272
	50	TOTAL:	610,638

* Compiled from Oklahoma Crude Production Report (Petroleum Information, 1984).

the Calvert, Romjue No. 1 well in the Northwest Avard field (31-27N-15W). It was completed as a gas producer in November 1959. The perforated interval was 4893-4928 feet. After a 1000 gallon acid treatment, the well gauged 8,060,000 CFGPD Open flow potential was 13,875,000 CFGPD with 14 barrels of 55° condensate per MMCF. Shut-in tubing pressure was 1720 psi (Curtis & Scott, 1963).

The Northwest Avard field is the largest Tonkawa producing field in Woods County (Tables V & VI). Curtis and Scott (1963) did a study on a small part of the field (Figure 48). They describe the trap as a result of a "sand lobe... projecting updip into a shale facies." In terms of paleoenvironments, these might be channel-mouth bar sands that are pinching out into an interdistributary bay facies. Figure 49 illustrates the extent of this interdistributary facies tract. Production occurs downdip of the contact between this facies and the sand facies (Cross section F-F', Plate 1). Any nosing of the Haskell limestone, such as that mapped by Curtis and Scott (1963), is presumed to be a secondary factor (Figure 48).

Future Production

The Tonkawa has been a fairly good gas producer on the north shelf area of Oklahoma. The biggest problem with the unit, however, is that it is poorly understood. This is because the Tonkawa is seldom the primary target in exploration. Usually, deeper deposits are targeted. The

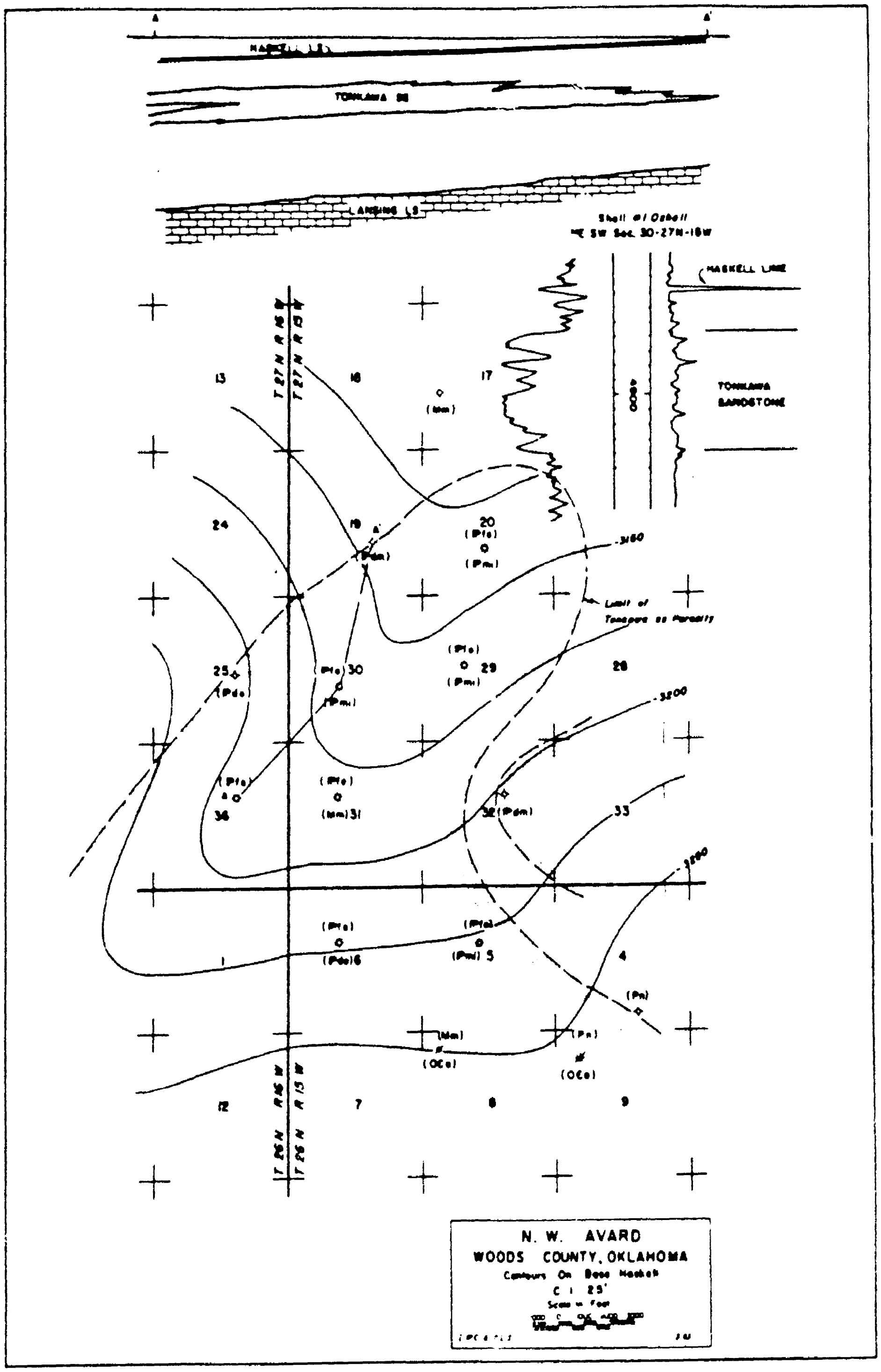


Figure 48. Structure Map and Cross Section of a Portion of Northwest Avard Field (from Curtis & Scott, 1963).

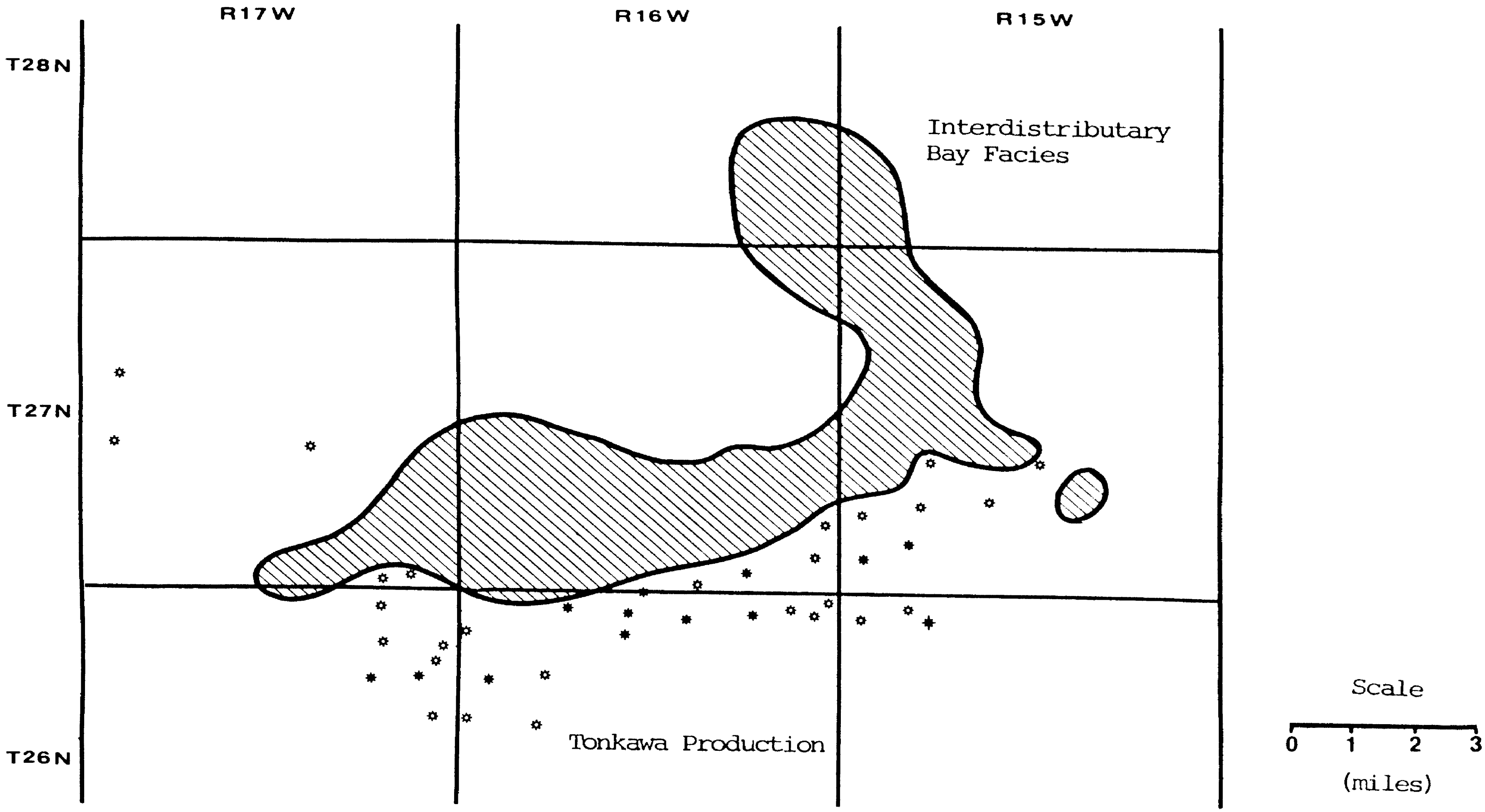


Figure 49. Map Showing Extent of Interdistributary Bay Facies Tract in Northwest Avard Field.

Tonkawa interval is routinely looked at on electric logs and, if it appears attractive, only then is it tested for hydrocarbons.

Most traps in the Tonkawa interval are stratigraphic and result from the pinching out of sands into shale facies in an updip direction. The majority of these sands probably are stream-mouth bar facies deposits.

The basic trends are known to be east-northeast to west-southwest, but a better understanding of the environments of deposition is needed to intelligently pick new exploration locations.

Careful mapping and electric log examination will assist in making proper interpretations as to what the various facies are and of how they relate to each other. From this work, more reliable predictions can be made.

CHAPTER X

SUMMARY

The following is a summary of the conclusions derived from this study:

1. The Tonkawa sands are present over most of the study area. The various sands can be divided into four packages, based on lateral facies relationships and relative stratigraphic position.

2. Subsurface mapping and core studies of the sands suggest a high-constructive lobate delta depositional environment. The study area probably represents a part of the lower plain in the delta complex.

3. The structure on the Haskell and Avant limestones shows a gentle generally southward dip into the Anadarko Basin. A series of broad, gentle north-south trending anticlines and synclines are present on each limestone. The Avant also shows very discrete anticlines and synclines trending in a northwest-southeast direction. Paleoslopes were also gentle, except near the carbonate shelf, where the slope increased significantly.

4. Stratigraphic pinching out of sand bodies in an updip direction are the main trapping mechanisms. Most of these sands probably are distributary-mouth bar deposits.

Structural traps are rare in the study area.

5. The Tonkawa sandstones in the area are classified as subrounded, fine- to very fine-grained, sublithic arenites. Muscovite clasts are the dominant accessory detrital mineral.

6. Porosity ranges from 0 to 14% and is almost wholly secondary. Authigenic calcite and siderite constitute the major pore filling constituents. Diagenetic chlorite, kaolinite, and illite are present but only in minor amounts.

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and the Tonganoxie ("Stalnaker") Sandstone in South-Central Kansas: Kansas Geological Survey Bulletin 127, p. 123-152.

VITA

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Master of Science

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Education: Graduated from Romulus Central School, Romulus, New York, in June 1975; received the Bachelor of Arts degree in Geology from California State University, Chico in December, 1982; completed requirements for the Master of Science degree at Oklahoma State University in May, 1988.

Professional Experience: Junior Geologist, Donald Herzog & Associates, Inc., Mill Valley, California, summer, 1982; Staff Geologist, Donald Herzog & Associates, Inc., Mill Valley, California, March, 1983 to August, 1985; Staff Geologist, John Hom & Associates, Inc., San Rafael, California, summer, 1986; Research Assistant, Department of Geology, Oklahoma State University, January, 1986 to May, 1986; Teaching Assistant, Department of Geology, Oklahoma State University, January, 1987 to May, 1988. Active member of the American Association of Petroleum Geologists; Member of the Oklahoma City Geological Society.

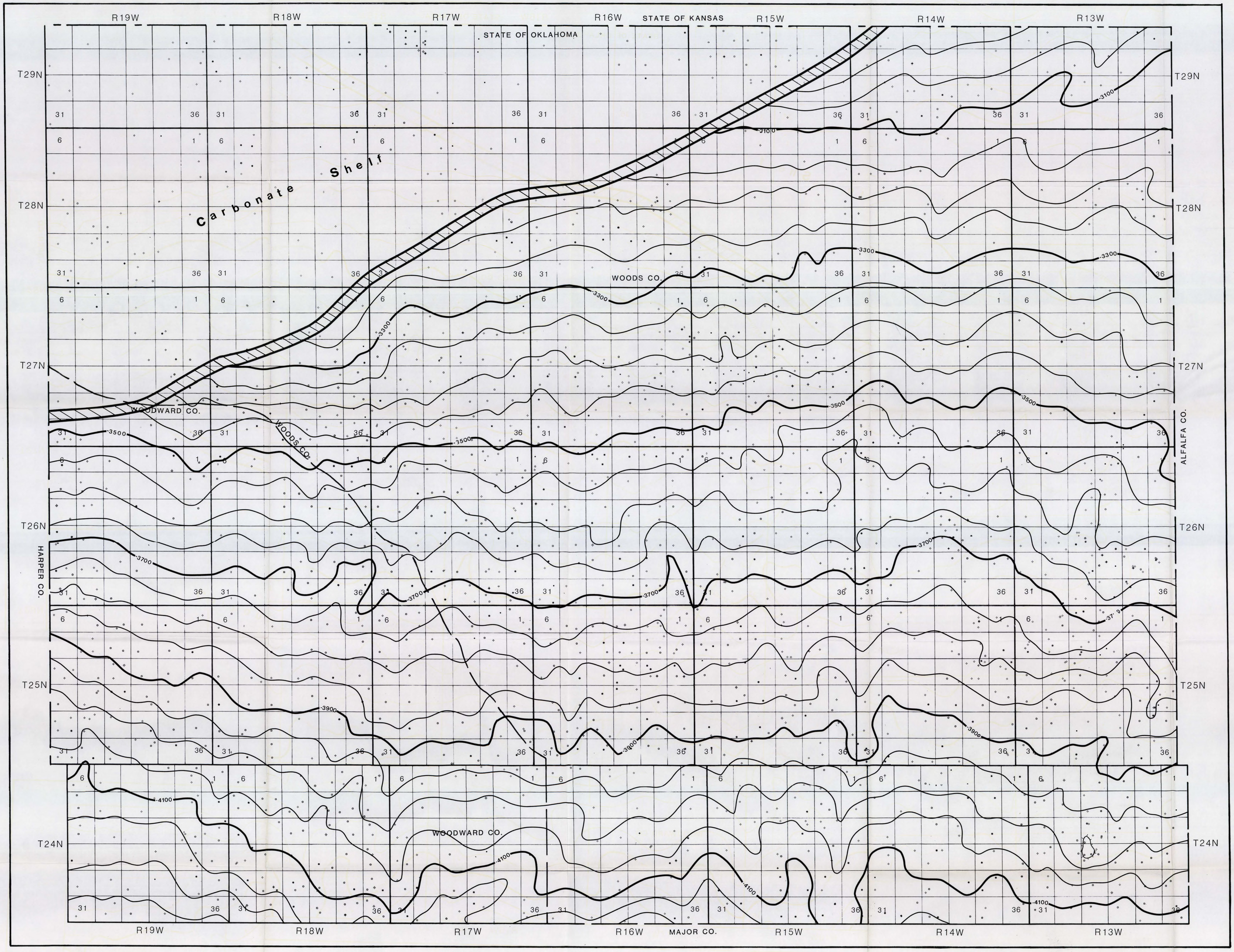
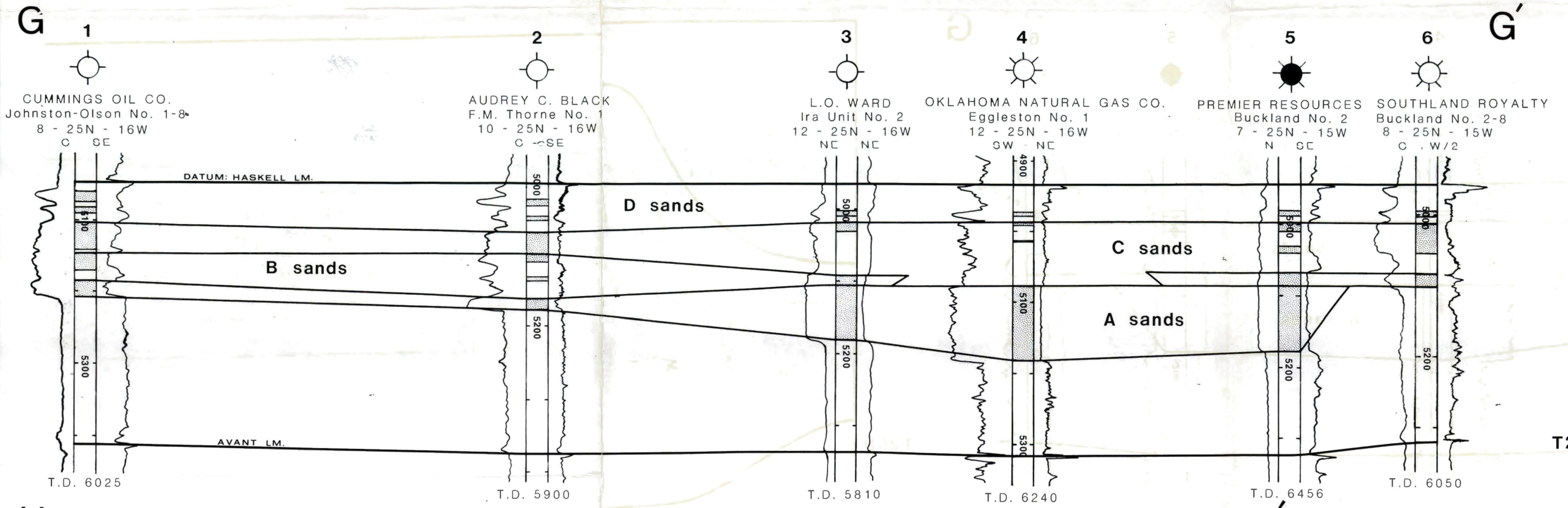


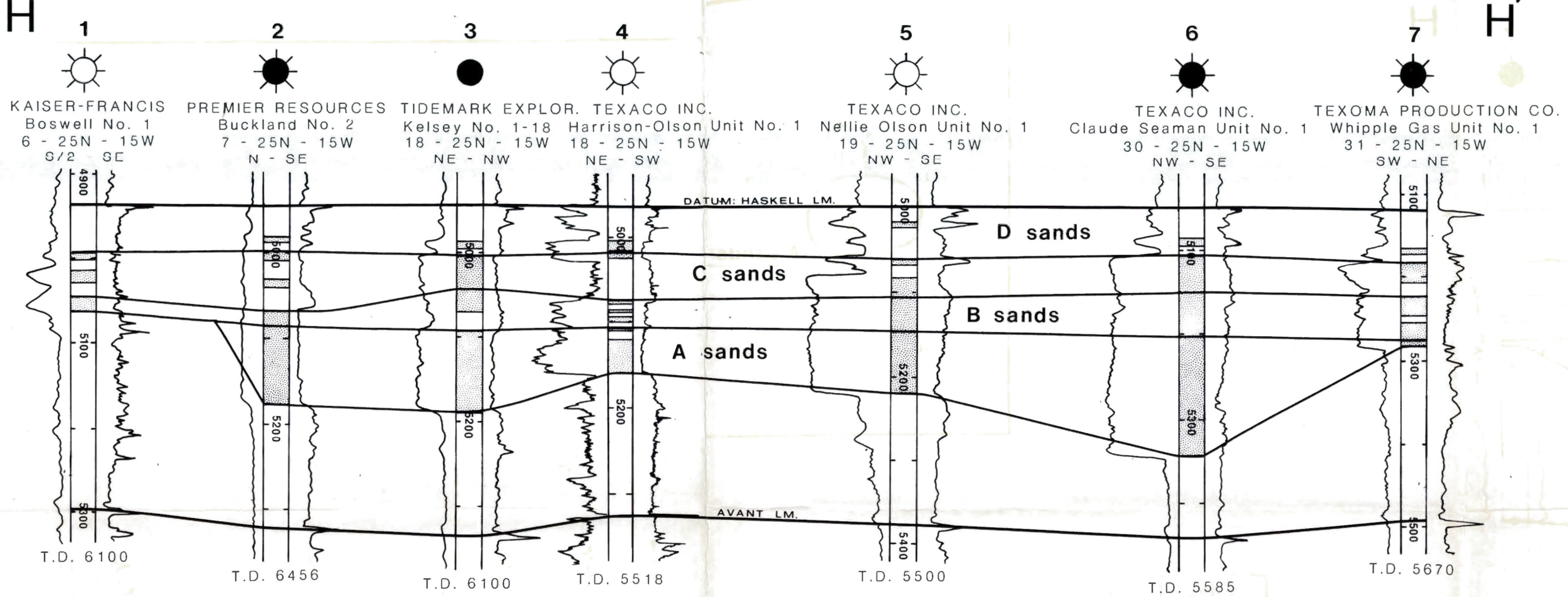
PLATE I
STRUCTURE CONTOUR MAP ON TOP OF AVANT LIMESTONE

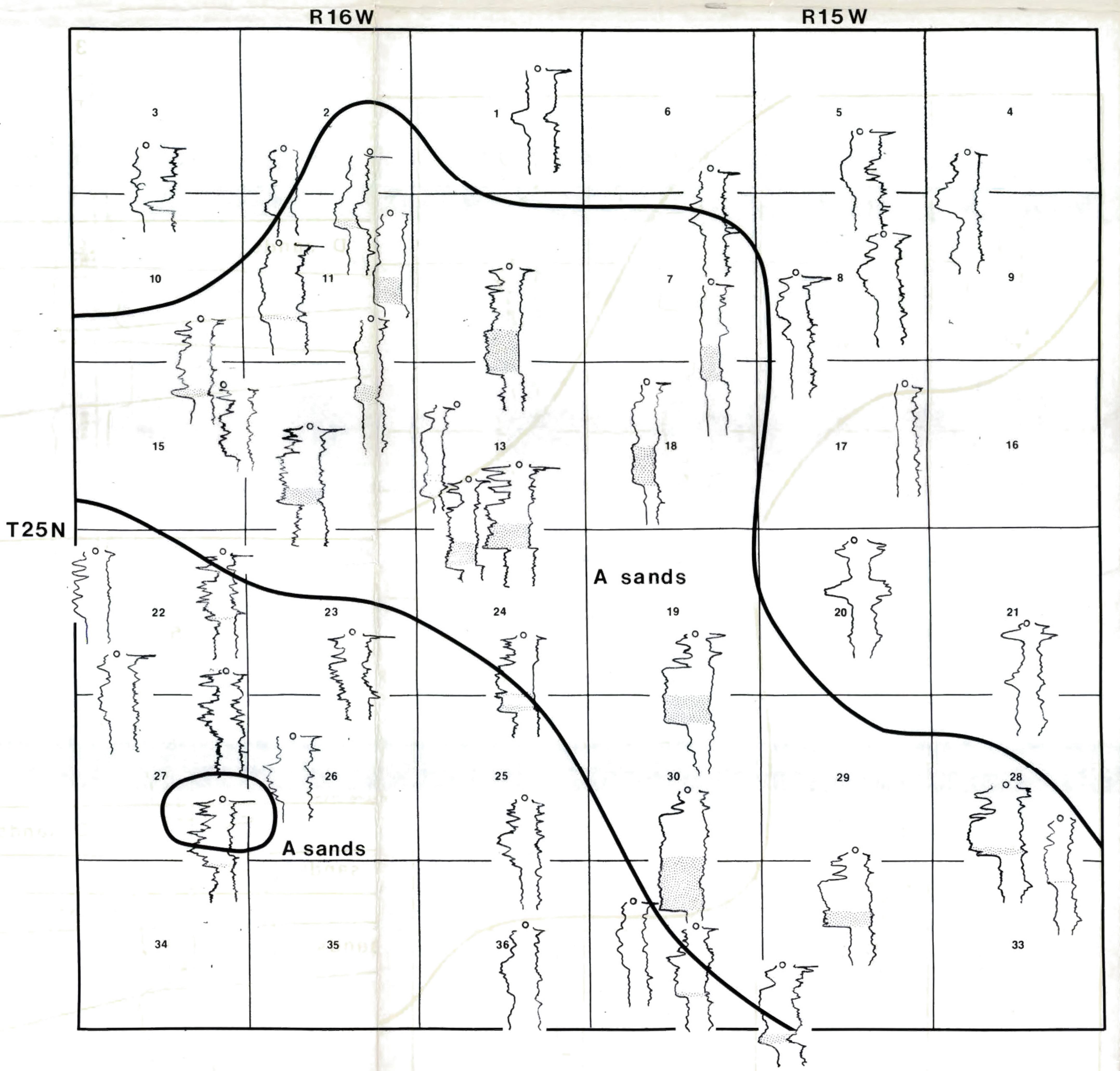
SCALE 0 ——— 2 Miles

C.I. 50'

M.W. Fies 1988







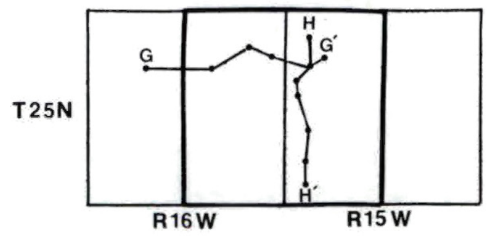


PLATE VIII

STRATIGRAPHIC CROSS SECTIONS G-G′ AND H-H′ AND LOG MAP 2 (TONKAWA SANDSTONES)

SCALE

CROSS SECTIONS: 0 – 1 Mile; 100 Feet

LOG MAP: 0 – .5 – 1 Mile

M.W. Fies 1988

PLATE VII

STRATIGRAPHIC CROSS SECTIONS C-C′, D-D′, AND E-E′

M.W. Fies 1988

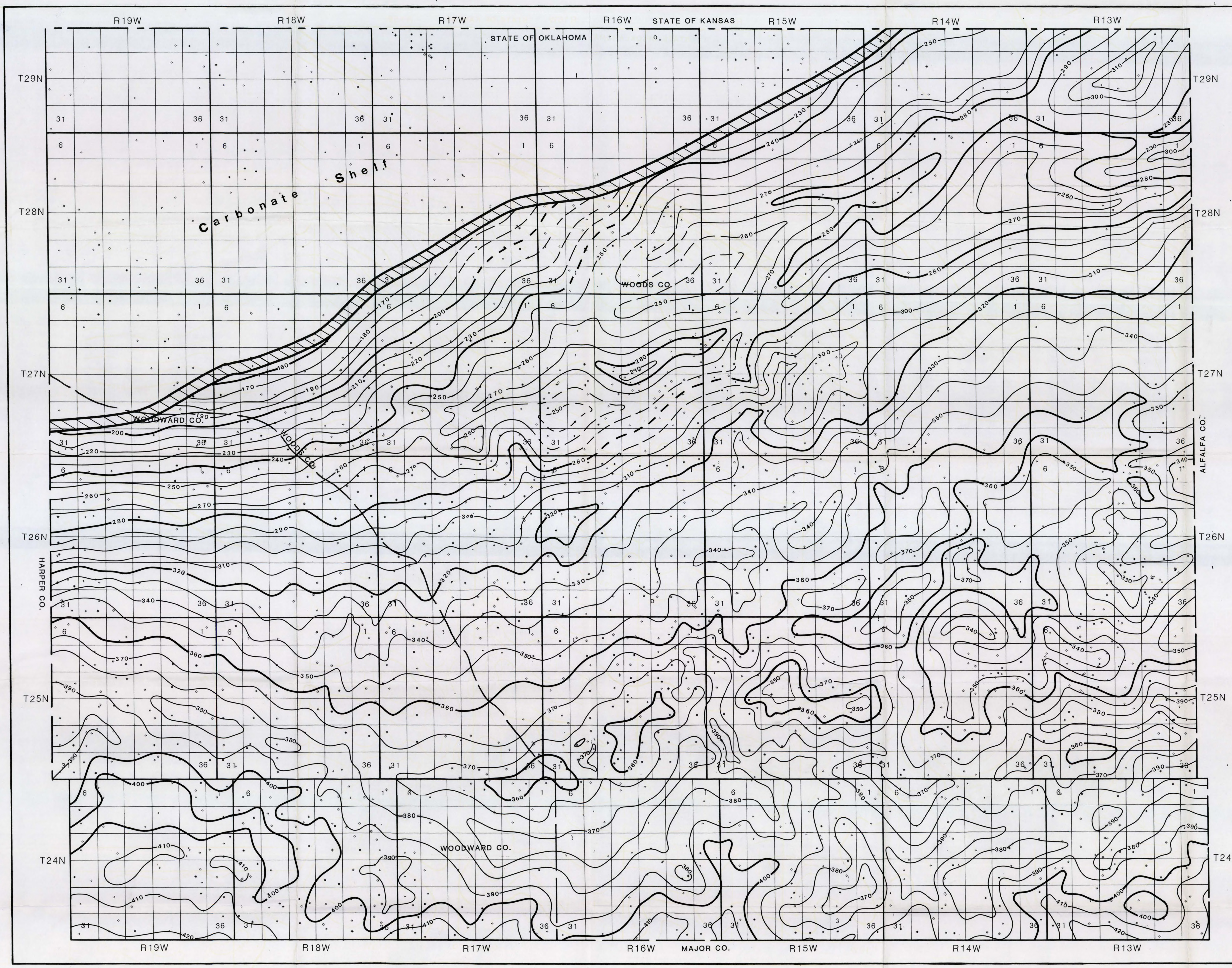


PLATE III
ISOPACH MAP OF THE TONKAWA FORMAT

SCALE 0 — 2 Miles

C.I. 10'

CONTOUR LINES DASHED WHERE ISOPACH THICKNESS IS INFERRED

M.W. Fies 1988

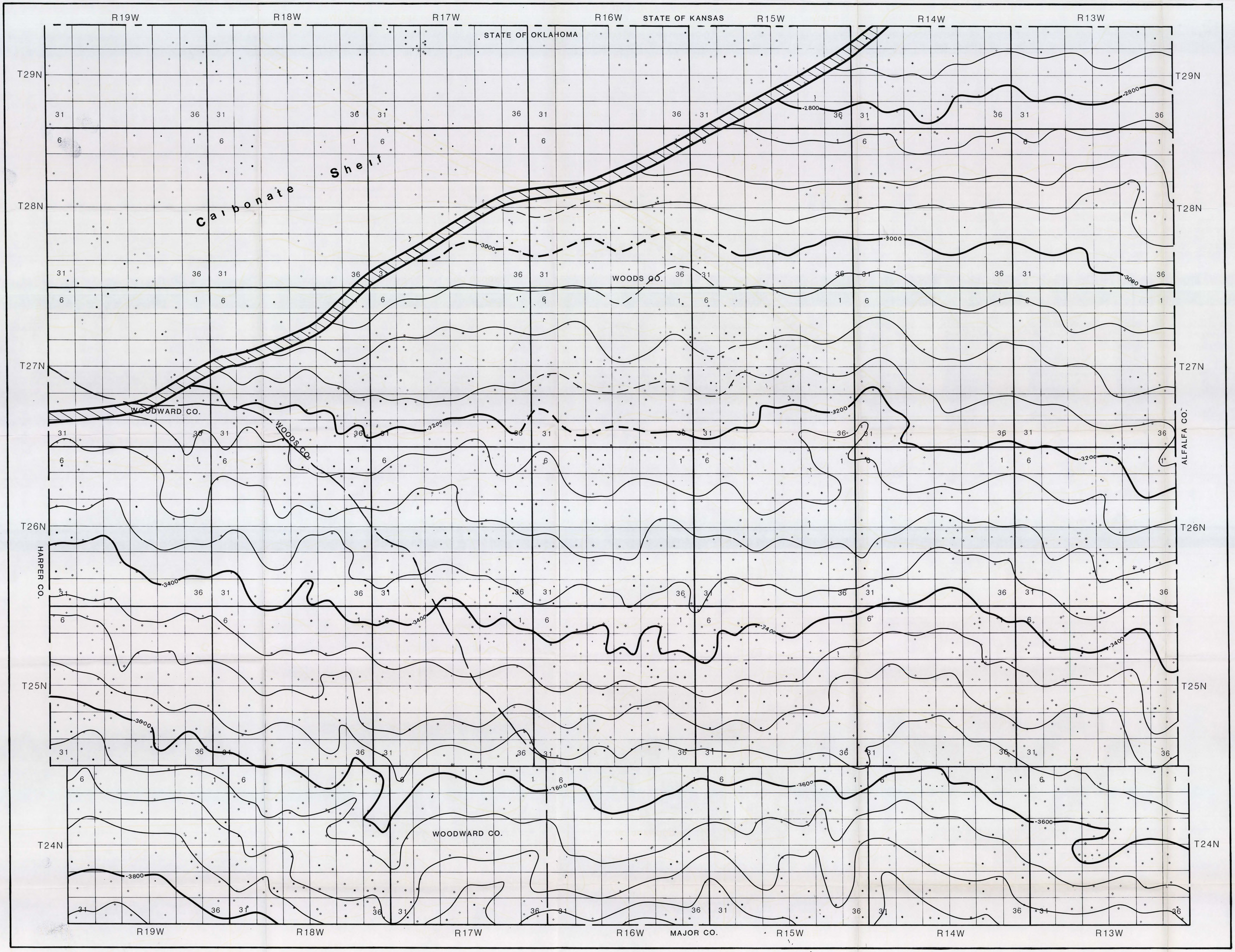


PLATE II
CONTOUR MAP ON TOP OF
HASKELL LIMESTONE

SCALE 0 — 2 Miles

C.I. 50'

CONTOUR LINES DASHED WHERE TOP OF HASKELL LIMESTONE IS INFERRED

M.W. Fies 1988

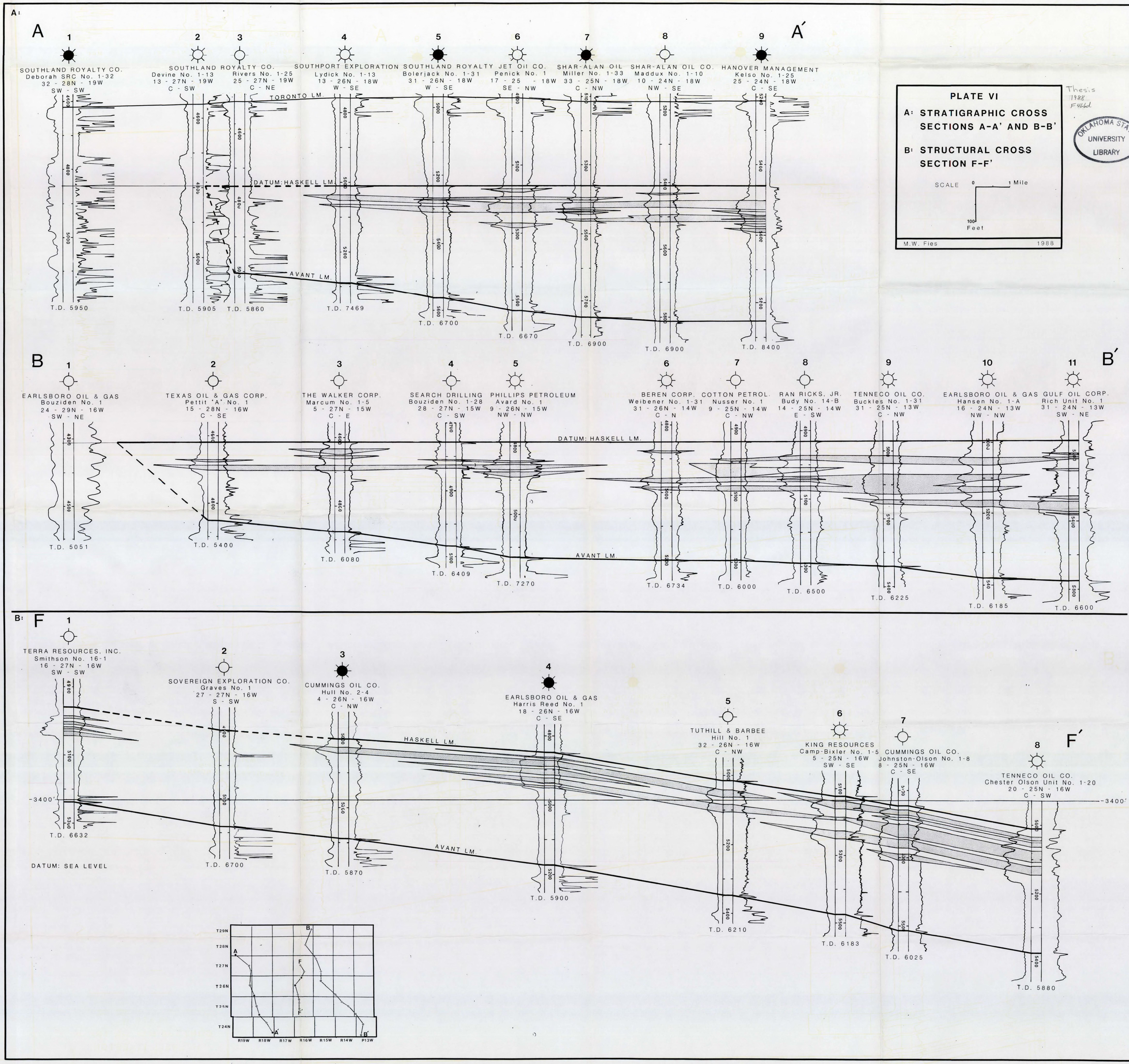


PLATE VI
A: STRATIGRAPHIC CROSS SECTIONS A-A' AND B-B'
B: STRUCTURAL CROSS SECTION F-F'
SCALE 0 1 Mile
100 Feet
M.W. Fies
1988
A
A'
1 SOUTHLAND ROYALTY CO. Deborah SRC No. 1-32 32 - 28N - 19W SW - SW
2 SOUTHLAND ROYALTY CO. Devine No. 1-13 13 - 27N - 19W C - SW
3 Rivers No. 1-25 25 - 27N - 19W C - NE
4 SOUTHPORT EXPLORATION Lydick No. 1-13 13 - 26N - 18W W - SE
5 SOUTHLAND ROYALTY Bolerjack No. 1-31 31 - 26N - 18W W - SE
6 JET OIL CO. Penick No. 1 17 - 25 - 18W SE - NW
7 SHAR-ALAN OIL Miller No. 1-33 33 - 25N - 18W C - NW
8 SHAR-ALAN OIL CO. Maddux No. 1-10 10 - 24N - 18W NW - SE
9 HANOVER MANAGEMENT Kelso No. 1-25 25 - 24N - 18W C - SE
TORONTO LM.
DATUM: HASKELL LM.
AVANT LM.
T.D. 5950
T.D. 5905
T.D. 5860
T.D. 7469
T.D. 6700
T.D. 6670
T.D. 6900
T.D. 6900
T.D. 8400
B
B'
1 EARLSBORO OIL & GAS Bouziden No. 1 24 - 29N - 16W SW - NE
2 TEXAS OIL & GAS CORP. Pettit "A" No. 1 15 - 28N - 16W C - SE
3 THE WALKER CORP. Marcum No. 1-5 5 - 27N - 15W C - E
4 SEARCH DRILLING Bouziden No. 1-28 28 - 27N - 15W C - SW
5 PHILLIPS PETROLEUM Avard No. 1 9 - 26N - 15W NW - NW
6 BEREN CORP. Weibener No. 1-31 31 - 26N - 14W C - N
7 COTTON PETROL. Nusser No. 1 9 - 25N - 14W C - NW
8 RAN RICKS, JR. Budy No. 14-B 14 - 25N - 14W E - SW
9 TENNECO OIL CO. Buckles No. 1-31 31 - 25N - 13W C - NW
10 EARLSBORO OIL & GAS Hansen No. 1-A 16 - 24N - 13W NW - NW
11 GULF OIL CORP. Rich Unit No. 1 31 - 24N - 13W SW - NE
DATUM: HASKELL LM.
AVANT LM.
T.D. 5051
T.D. 5400
T.D. 6080
T.D. 6409
T.D. 7270
T.D. 6734
T.D. 6000
T.D. 6500
T.D. 6225
T.D. 6185
T.D. 6600
F
F'
1 TERRA RESOURCES, INC. Smithson No. 16-1 16 - 27N - 16W SW - SW
2 SOVEREIGN EXPLORATION CO. Graves No. 1 27 - 27N - 16W S - SW
3 CUMMINGS OIL CO. Hull No. 2-4 4 - 26N - 16W C - NW
4 EARLSBORO OIL & GAS Harris Reed No. 1 18 - 26N - 16W C - SE
5 TUTHILL & BARBEE Hill No. 1 32 - 26N - 16W C - NW
6 KING RESOURCES Camp-Bixler No. 1-5 5 - 25N - 16W SW - SE
7 CUMMINGS OIL CO. Johnston-Olson No. 1-8 8 - 25N - 16W C - SE
8 TENNECO OIL CO. Chester Olson Unit No. 1-20 20 - 25N - 16W C - SW
HASKELL LM.
AVANT LM.
-3400'
DATUM: SEA LEVEL
T.D. 6632
T.D. 6700
T.D. 5870
T.D. 5900
T.D. 6210
T.D. 6183
T.D. 6025
T.D. 5880
T29N T28N T27N T26N T25N T24N
R19W R18W R17W R16W R15W R14W R13W

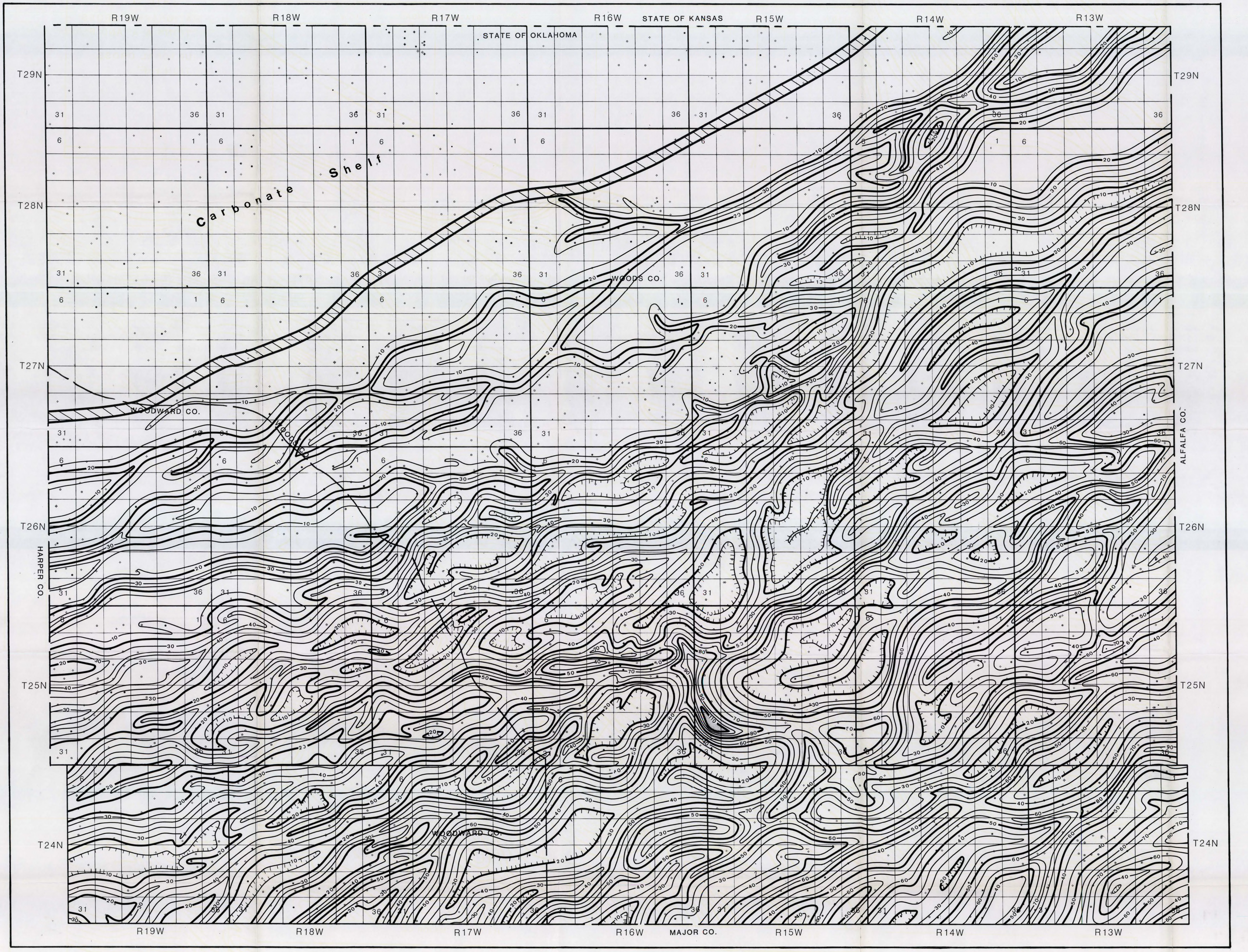


PLATE IV
NET SANDSTONE ISOLITH MAP
OF THE TONKAWA FORMAT

SCALE 0 2 Miles

C.I. 10'

TOTAL SAND THICKNESS BETWEEN 110' and 230'

M.W. Fies 1988

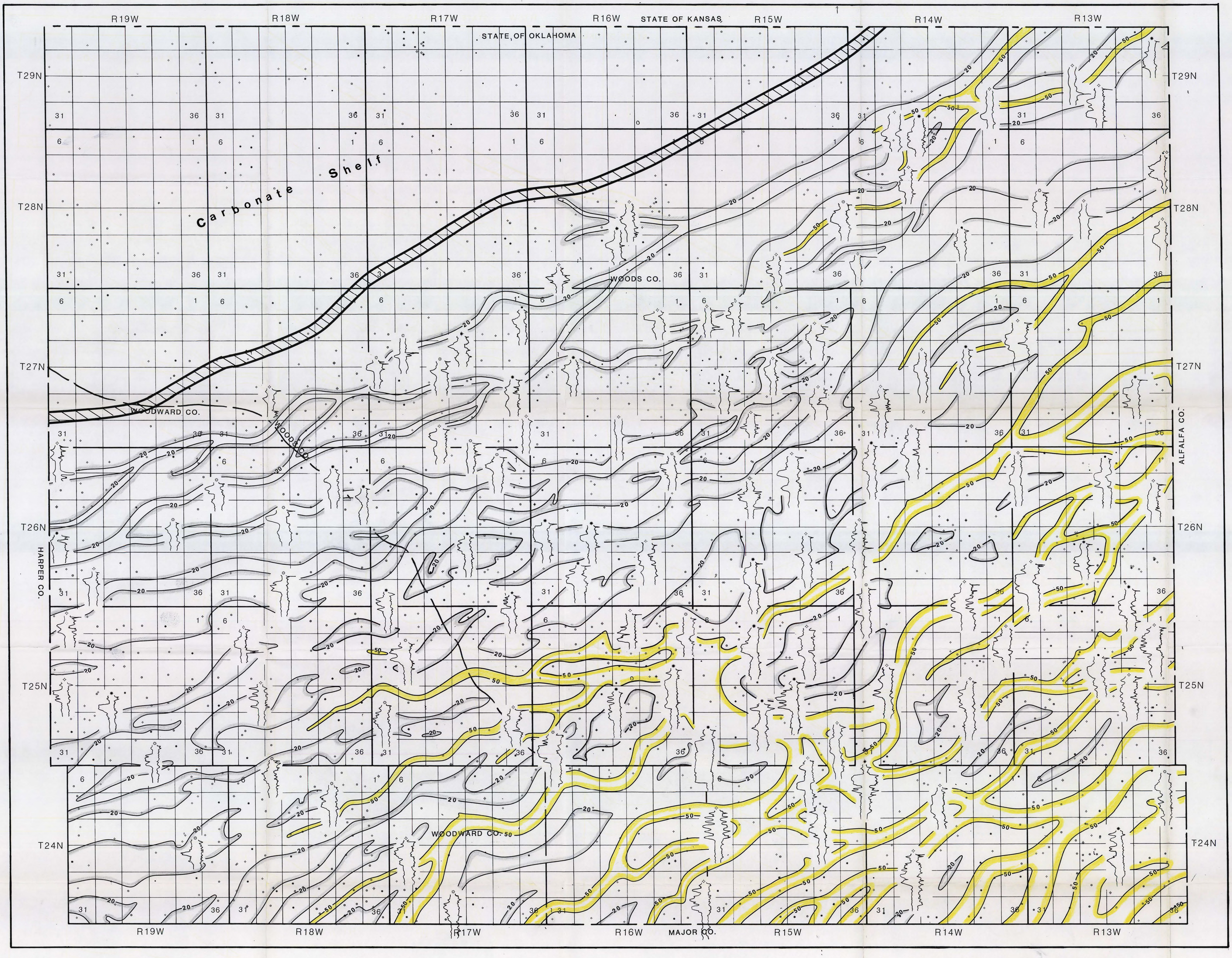


PLATE V
LOG MAP 1
(TONKAWA SANDSTONES)

SCALE 0 — 2 Miles

SAND THICKNESS GREATER THAN 50'

SAND THICKNESS LESS THAN 20'

M.W. Fies 1988