PETROLOGY, DIAGENESIS AND DEPOSITIONAL ENVIRONMENT OF THE TONKAWA SANDSTONE IN SOUTHWESTERN DEWEY COUNTY, OKLAHOMA

By

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CHAPTER I

ABSTRACT

The Pennsylvanian Tonkawa Sandstone of the Douglas Group of the Virgilian Series was studied in southwestern Dewey County, Oklahoma. Techniques employed included stratigraphic cross-section preparation, structural and isopachous mapping, analysis of core, and thin-section microscopy coupled with X-Ray diffraction.

The Tonkawa Sandstones are present primarily as elongate and coalescing lobes which are thought to record deposition in deltaic environments during overall regression. Important Tonkawa Sandstone reservoir facies are interpreted to be distributary mouth bars and distributary channel fill sandstones.

The Tonkawa Sandstones are very fine and fine grained, and moderately to well sorted. They classify as sublitharenites. Monocrystalline and polycrystalline quartz, metamorphic rock fragments, feldspars, and muscovite are the main constituents. Diagenesis has led to four major cementing minerals including silica, dolomite, calcite, and siderite. These cements are present in highly variable amounts.

Chlorite is the most abundant authigenic clay mineral

in the Tonkawa Sandstone. Kaolinite is locally abundant. Authigenic illite is a minor constituent.

Porosity in the Tonkawa is mostly secondary. The development of secondary porosity is largely due to the dissolution of feldspars, fossil fragments, and carbonate cements.

CHAPTER II

INTRODUCTION

This study is a subsurface investigation of the Tonkawa Sandstone in Dewey County, Oklahoma. The study area includes townships 16 through 18 north, ranges 16 through 20 west (Fig. 1).

Objectives

The purpose of this study is to document the sedimentologic, petrologic, and diagenetic characteristics of the Tonkawa Sandstone in the Anadarko Basin. The principal objectives of this investigation are: 1) to provide an interpretation concerning the depositional environment of the Tonkawa Sandstone; 2) to analyze the petrologic composition of the Tonkawa; and 3) to determine the sequence of diagenetic events which have affected the Tonkawa Sandstones and study the porosity development of the sandstone.

Methods and Procedures

The Tonkawa Sandstone is contained within a sequence of strata defined at the base by the Avant Limestone and at the top by a "hot-shale" gamma ray marker overlying the

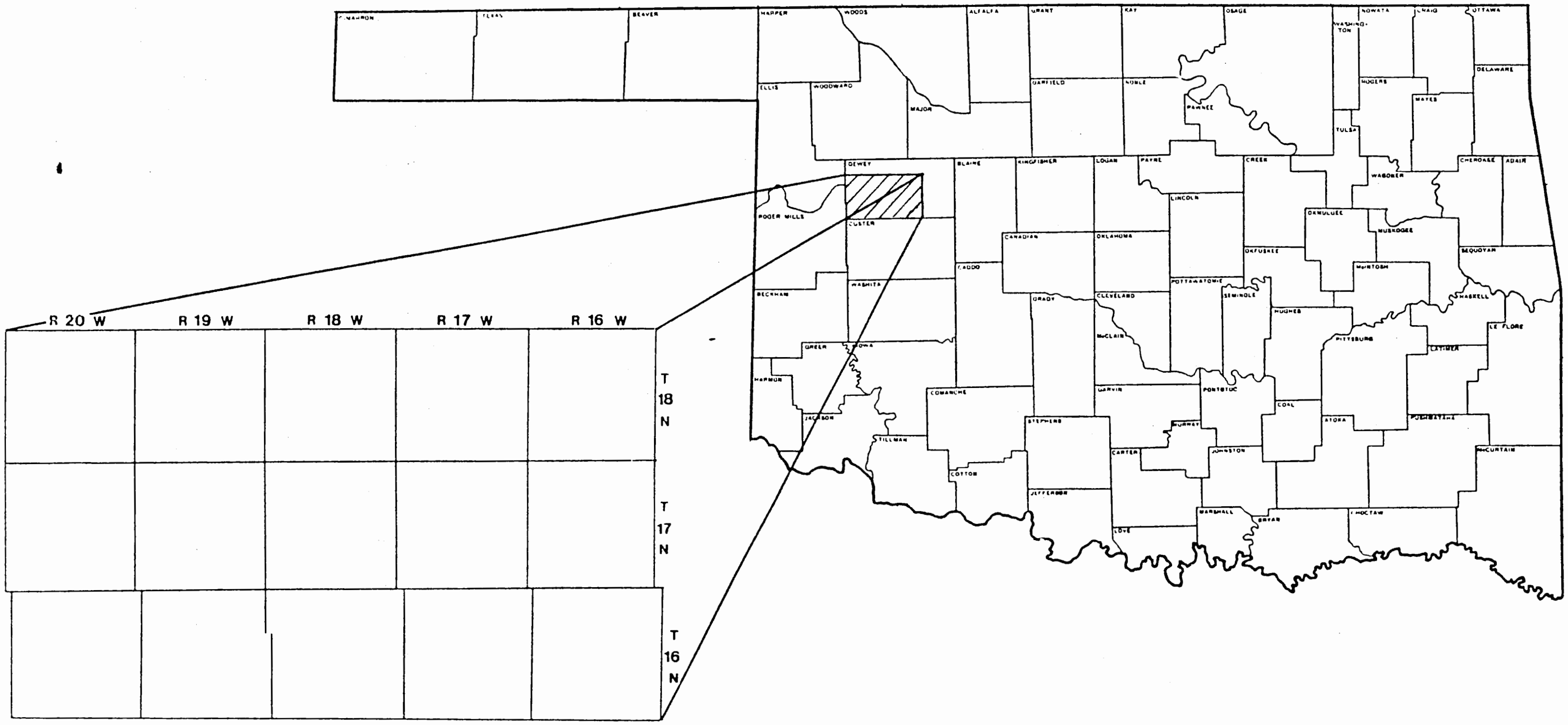

Figure 1. Location of Study Area.

Haskell Limestone (Fig. 2). This "hot-shale" marker is termed the Haskell Marker in this study. The interval defined by the top of the Avant Limestone and by the base of the Haskell Marker is termed the Tonkawa Interval.

Six stratigraphic cross-sections of the Tonkawa Interval were constructed to illustrate the vertical and lateral relationships and well-log signature patterns of the Tonkawa Sandstone. Three of the cross-sections are oriented along structural strike (Plates I - III) and three of the cross-sections are oriented along structural dip (Plates IV - VI). The cross-section locations are illustrated (Fig. 3).

A structural contour map on the base of the Haskell Marker (Plate VII) and an isopach map of the Tonkawa Interval (Plate VIII) were constructed to illustrate the geometry of the interval. Well control for this study amounted to over 95% of all well-logs available from the area prior to January, 1987.

Comparisons between lithologies in core and their gamma ray log response demonstrated that sandstone of potential reservoir quality is indicated at -45 API units of deflection from an averaged "shale base line". The net thickness of sandstone was then summed and a net-sandstone isopach map was constructed to illustrate sandstone distribution and trends (Plate IX).

A suite of cores were obtained, analyzed, and sampled. Lithologies, sedimentary structures, textures, and their

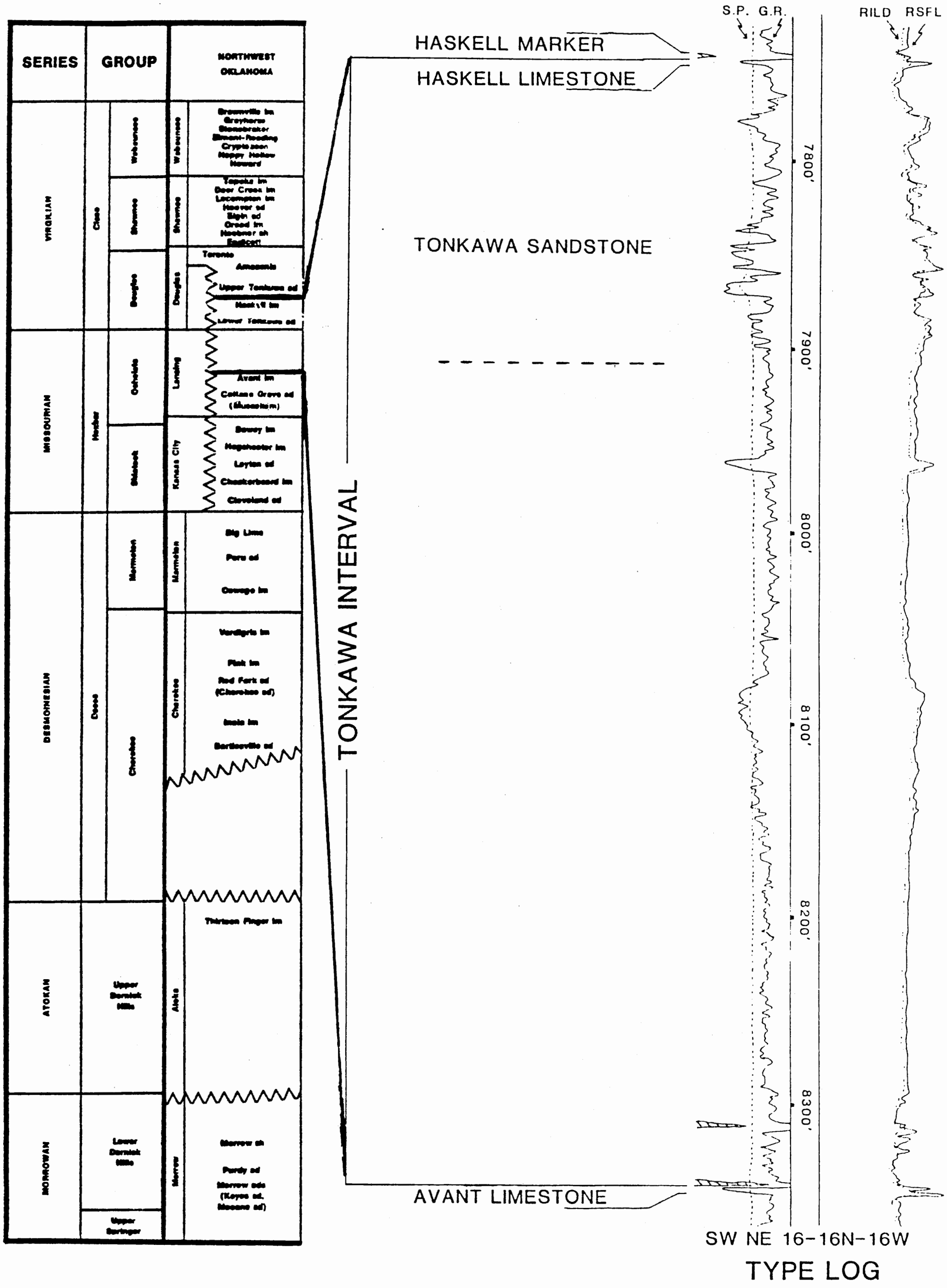

Figure 2. Type Log of Tonkawa Interval.

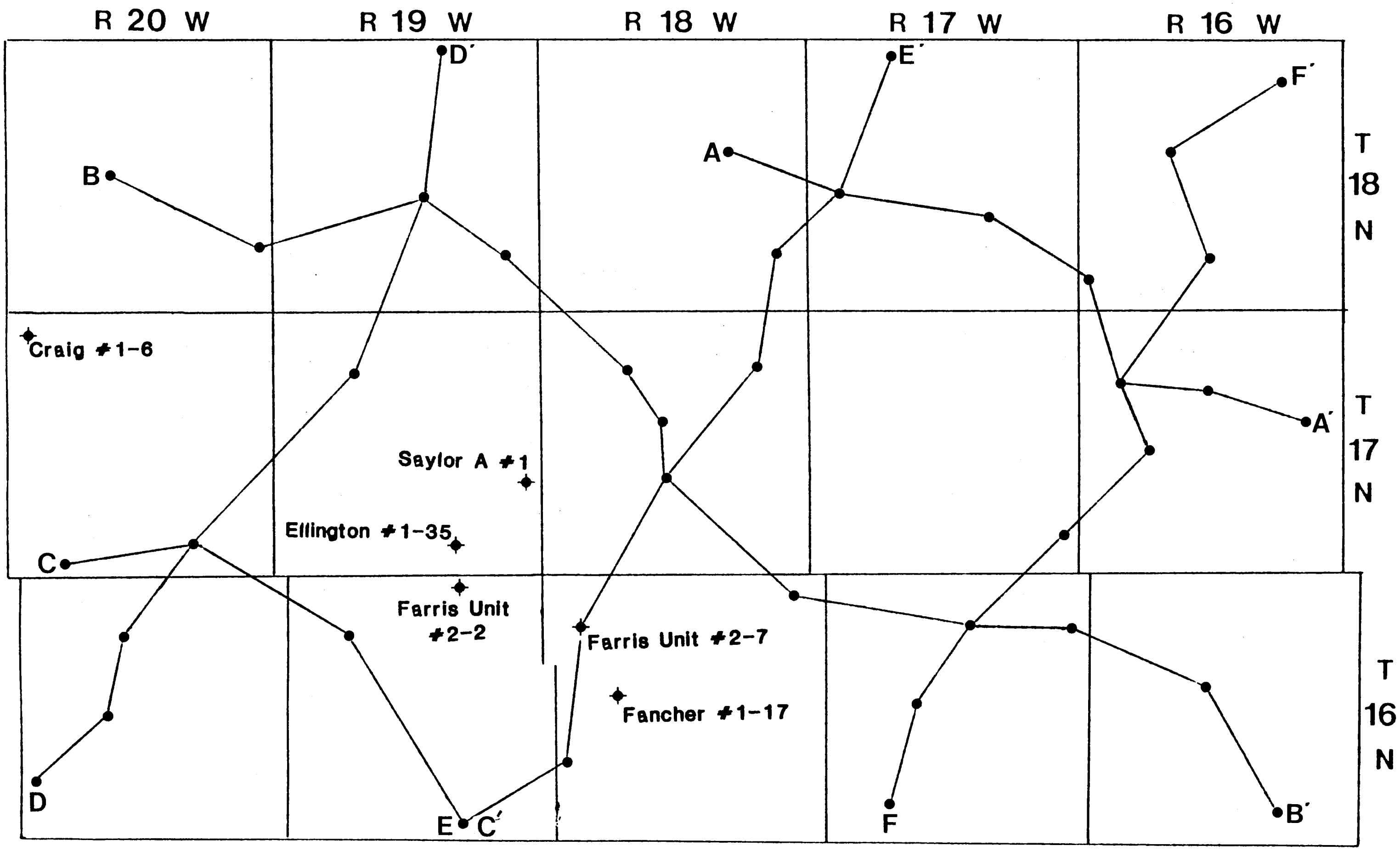

Figure 3. Index Map of Cross-Section and Core Locations.

vertical sequences were recorded (Appendix). The locations of the cores are illustrated (Fig. 3).

Routine thin-section examination using standard petrographic microscopy allowed the quantitative determination of detrital and authigenic constituents in the Tonkawa Sandstone. Each thin-section was point counted for a total of 400 points. X-Ray diffraction analysis of powdered and "clay-extracted" (Kittrick and Hope, 1963) samples was done to provide support for mineralogical determinations made in thin-section analysis. "Clay-extracted" samples were run in their natural, heated, and glycolated states for accurate identification of clay minerals (Carroll, 1970). Sample locations are included with petrologic logs (Appendix).

Previous Investigations

Although a large number of publications make reference to the Tonkawa Sandstone, only a few have included detail discussions. The following are those articles which included indepth investigations of the Tonkawa which are deemed appropriate to this study.

Clark and Aurin (1924) and Hosterman (1924) demonstrated that the Tonkawa Sandstone produces oil from anticlinal traps in the Tonkawa Field of Kay County, Oklahoma. The Tonkawa Sandstone was named after this field (Jordan, 1957).

Pate (1959) included the Tonkawa in a study of stratigraphic traps in northwest Oklahoma. He demonstrated that hydrocarbon production occurs along the northern limits of sandstone distribution in that area.

Khaiwka (1968) mapped what he termed the "upper member" of the Tonkawa Sandstone in Beaver County, Oklahoma. He described two laterally coalescing deltaic lobes (also see Busch, 1971).

Lane (1978) studied the stratigraphic relationship of the Tonkawa Sandstone and the Missourian Lansing Group carbonates in Beaver County, Oklahoma. He argued that the Tonkawa is in the "foreset-slope sediments" of the Douglas Group, Virgilian Series, and does not represent a facies change of the Lansing, which was originally suggested by Pate (1959). His argument was based in part on biostratigraphic evidence.

Kumar and Slatt (1984) applied a shelf to basin slope depositional model to the Tonkawa Sandstone in an area adjacent to and including much of this study area.

Fies (1988) studied the Tonkawa in Woods and portions of Woodward Counties, Oklahoma. He believed the Tonkawa Sandstone was deposited in a deltaic environment. His work is the only previous study which included a detailed investigation of the petrology and diagenesis of the Tonkawa.

CHAPTER III

STRUCTURAL FRAMEWORK

The Anadarko Basin is an elongate asymmetrical feature with a west-northwest trending axis which is located in western and southwestern Oklahoma. The southern margin is a complex fault system which abruptly seperates the basin from the nearby Amarillo-Wichita Uplift (Evans, 1979). The northern flank of the basin extends from western Oklahoma into Kansas and the Texas Panhandle. The Anadarko Basin is bounded to the east by the Nemaha Ridge, to the north by the Central Kansas Uplift, and to the northwest by the Apishapa-Sierra Grande Uplift (Moore, 1979). The study area is situated on the northern flank of the Anadarko Basin approximately 50 miles north-northeast in a perpendicular direction from the axis of the basin (Fig. 4).

The Anadarko Basin is the largest element of several west-northwest trending basins and uplifts located between the Ouachita Mountains of southeastern Oklahoma and the Sierra Grande Uplift of northeastern New Mexico (Fig. 4). This area was first described as an example of an aulacogen by Schatski (1946). Using concepts explained by Burke and Dewey (1973) an aulacogen can be divided into three stages;

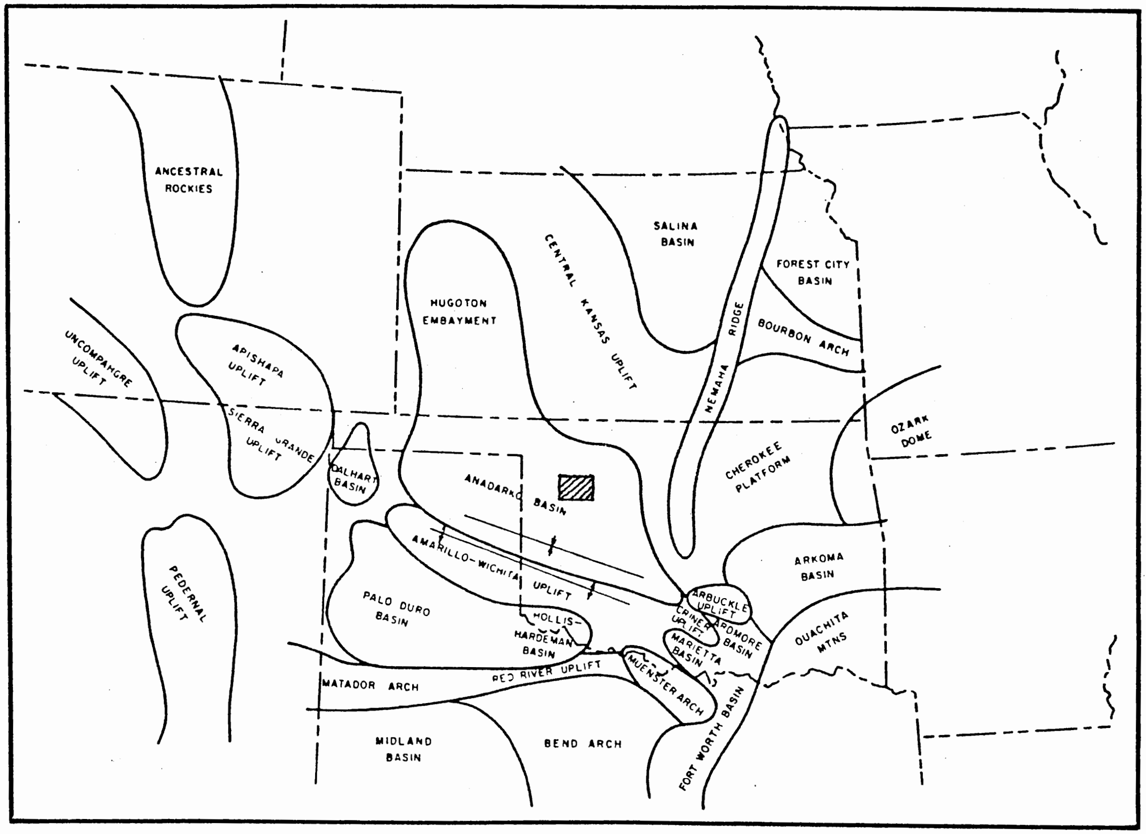

Figure 4. Location of Study Area in Physiographic Framework of Mid-Continent (from Moore, 1979, fig. 1, pp. 3).

an early rifting stage, a subsiding stage, and a later deformation stage. The rifting stage, from late Precambrian through Middle Cambrian, was associated with igneous activity and graben formation (Feinstein, 1981). The subsiding stage is reflected in Late Cambrian through Devonian carbonate and clean, well-sorted sandstone deposition. The deformation stage resulted in fragmentation of the original large basin and formation of the numerous smaller basins which includes the Anadarko. This deformational stage is recorded by siliceous clastic rocks of Pennsylvanian age.

The concept of aulacogens and their formation has been applied to the Anadarko Basin in conjunction with collisions between the North American and South American Plates (Rascoe and Adler, 1983). Collisions between these plates may have produced deformation of the Ouachita Foldbelt, initiation of the Amarillo-Wichita and Nemaha Uplifts, and formation of the Anadarko Basin. The formation of the several uplifts and basins which characterize southern Oklahoma may have been largely controlled by fault lines of the original rift system. The initial collision between the plates may have marked the beginning of clastics dominated deposition in Early Pennsylvanian times.

Generalized Early Virgilian paleogeography reflects geomorphic configuration of tectonic features in the Mid-Continent during the approximate time of Tonkawa Sandstone

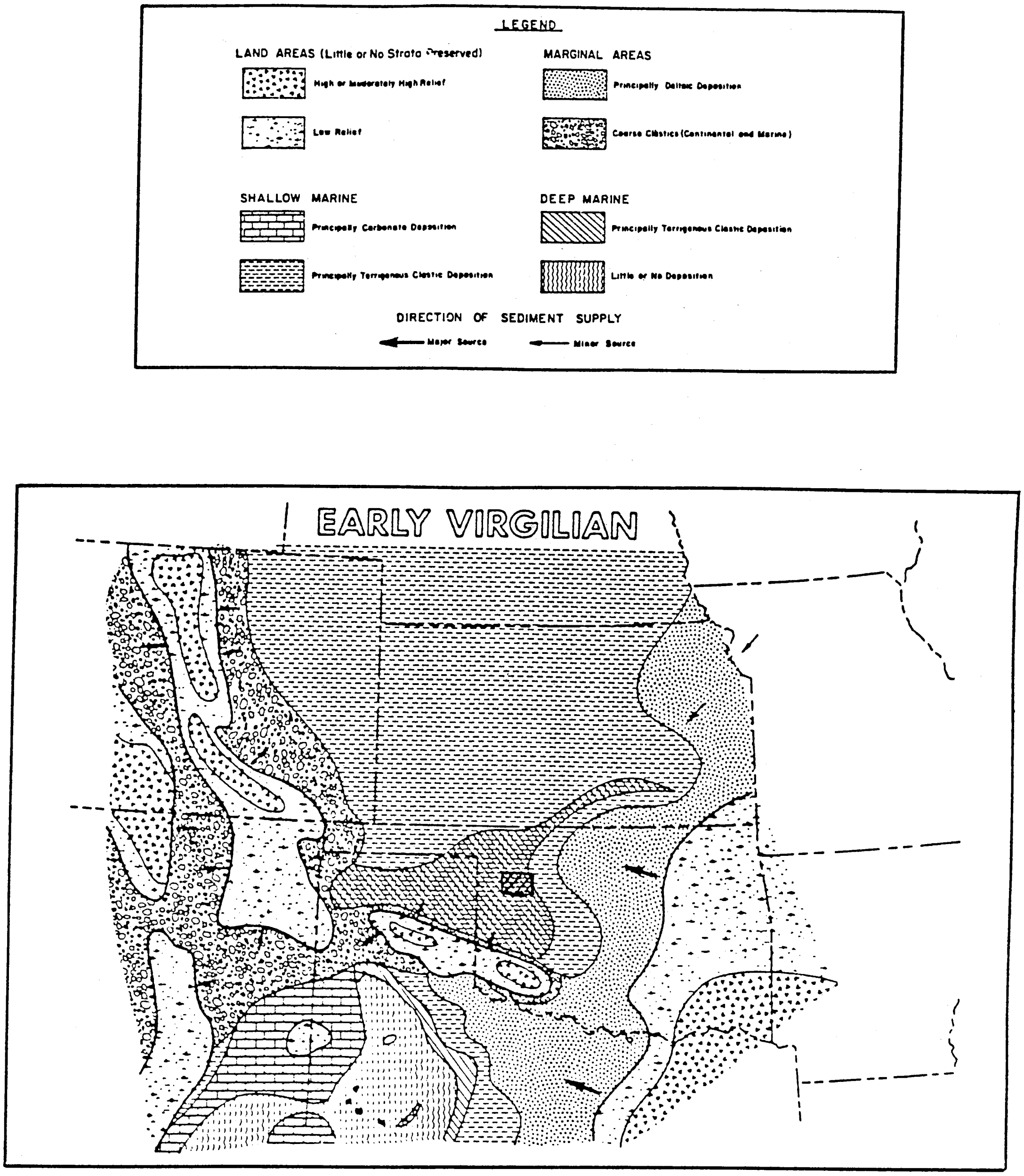

Figure 5. Location of Study Area in Early Virgilian Paleogeographic Framework of Mid-Continent (from Moore, 1979, fig. 10, pp. 11).

deposition (Fig. 5). Granite wash from the Amarillo-Wichita Uplift were being deposited into the subsiding Anadarko Basin and are segregated from the study area by the axial trough of the basin. The Ouachita Mountains provided a major source of clastic material for Oklahoma basins during the Missourian and Virgilian (Krumme, 1975). The Nemaha Ridge and Central Kansas Uplift, which formed major positive features in Early Pennsylvanian times, had been onlapped by strata of Desmoinesian and Missourian age within this region (Moore, 1979). An additional source of clastics existed to the northeast of the Mid-Continent region during Early Virgilian times (Lins, 1950; Winchell, 1957; Sanders, 1959; Griffith, 1981; Walton and Griffith, 1985).

Regional Structure on Top of Haskell Limestone

Gibbons (1962) produced a regional structural contour map on the Haskell Limestone across much of the Anadarko Basin (Fig. 6). This map shows a gentle homoclinal dip of approximately 30 feet per mile in a southerly direction to the north of the study area. This rate of dip increases slightly to approximately 50 feet per mile within the study area.

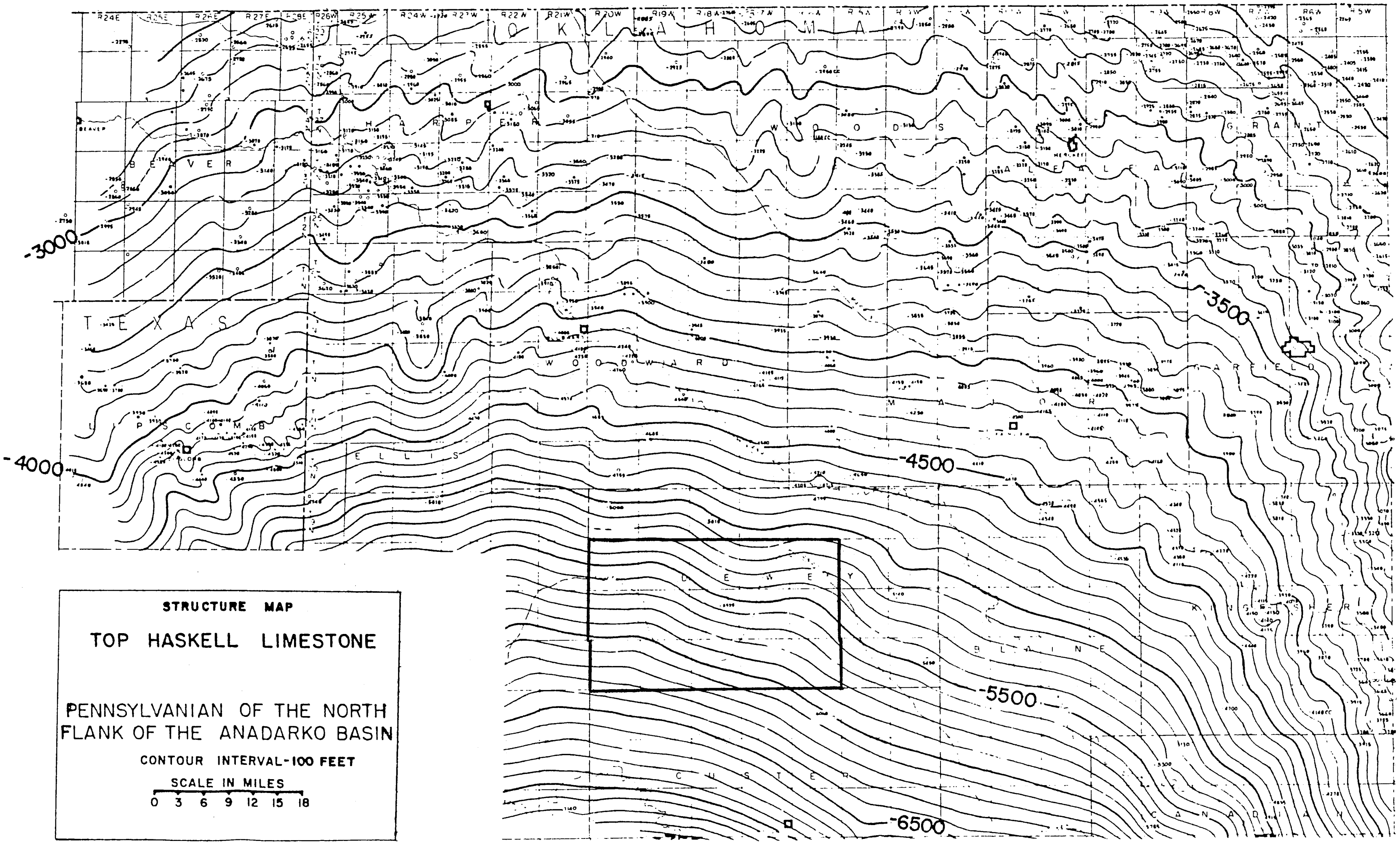

Figure 6. Regional Structure on Haskell Limestone (from Gibbons, 1962, plate 2, map 2).

Local Structure on Base of Haskell Marker

The structural contour map prepared on the base of the Haskell Marker shows gentle homoclinal dip to the south-southwest of approximately 50 feet per mile or 1/2 degree (Plate VII). This is punctuated by several anticlinal noses and synclinal troughs.

Three closures were identified. A large, apparently isolated, domal feature occurs in the northern portion of township 16 north, range 20 west. Maximum closure on this structure is approximately 55 feet. Two smaller closures occur along an anticlinal nose which trends from the northern portion of township 17 north, range 18 west to the south-sothwest. The closure in section 10, township 17 north, range 18 west was identified by Slate (1962) despite poor well control at the time of his study.

CHAPTER IV

STRATIGRAPHIC FRAMEWORK

The Tonkawa Sandstone is part of the Douglas Group of the Virgilian Series, Pennsylvanian System (Jordan, 1957). The Douglas Group is the lowermost lithostratigraphic subdivision of the Virgilian Series and includes strata from the base of the Tonkawa Sandstone to the top of the Toronto Limestone (Chenoweth, 1979).

The stratigraphic equivelant of the Tonkawa Sandstone is the Tonganoxie ("Stalnaker") Sandstone of Kansas (Lukert, 1949). Sandstones in the lower portions of the Vamoosa Group on the Cherokee Platform may also be stratigraphically equivelant to the Tonkawa (Frezon and Dixon, 1975), but correlations in that area are uncertain (Lukert, 1949; Ball, 1964). Below the Tonkawa Interval in the study area is the Cottage Grove Sandstone and above is the Lovell Sandstone. The Lovell is sometimes termed Upper Tonkawa or Douglas.

The Tonkawa Sandstone is present across much of the Anadarko Basin as a "sheet" or "blanket" sandstone of varying thickness (Rascoe, 1962; Frezon and Dixon, 1975). The study area is situated along the southeastern limits of this sheet in Dewey County, Oklahoma, where sandstone becomes less continuous (Rascoe, 1962).

Within the Tonkawa Interval in the study area are three distinct developments of sandstone (Fig. 2). This investigation is solely concerned with the Tonkawa Sandstone. The Tonkawa Sandstone is defined as the sequence of clastics between the base of the Haskell Marker and base of the lowermost sandstone body indicated at greater than -45 API units of deflection from an averaged "shale base line" on the gamma ray curve which occurs within 175 feet below the Haskell Marker. Sandstones below the Tonkawa in the eastern portions of the study area are not believed to be genetically related to the Tonkawa Sandstone (Rascoe, 1962). The lowermost of these sandstones was interpreted as a submarine fan complex by Kumar and Slatt (1984). The Tonkawa Sandstone of this study is contained within their Middle Tonkawa Sandstone.

The Tonkawa Interval is bounded by the Avant and Haskell Limestones (Fig. 2). These limestones have been noted as marker beds of regional extent in northwest Oklahoma (Jordan, 1957; Rascoe and Adler, 1983). The Haskell Limestone is poorly developed or absent across much of the western portions of the study area owing to non-deposition. However, the Haskell Marker is easily correlated across the area. This "hot-shale" marker overlies the Haskell Limestone, usually directly and always within approximately two feet, where the latter is present.

The Haskell Limestone is often reported as a fossiliferous and locally oolitic limestone across much of the Anadarko Basin (Winchell, 1957; Ball, 1964; Lane, 1978; Fies, 1988). In the Farris Unit # 2 - 2 core the Haskell was found to be a fossiliferous calcareous shale (Fig. 7). Fossils include brachiopods, crinoid columns, and microfossils. Slate (1962) reported oolites in this limestone in an early stratigraphic study of the Dewey County area. Strip logs also described the Haskell as oolitic, principally in the easternmost portions of the study area.

Cross-Sectional Network

The Tonkawa Interval shows overall thickening to the south and southeast within the study area (Plates I - VI). Interval thickness changes from roughly 480 feet along the northern edge to over 600 feet in the southwest and 640 feet in the southeast. The Tonkawa Sandstone remains within 150 feet below the Haskell Marker across the area. Changes in interval thickness are attributed to the section of shales and sandstones below the Tonkawa. The Tonkawa Sandstone is seperated from the sandstones below by thick shales within the study area. The sandstones below the Tonkawa are confined to the eastern six townships, in the west the interval below the Tonkawa contains no sandstone.

The thickest Tonkawa Sandstone developments occur in a zone which is between approximately 70 and 150 feet below the Haskell Marker across the study area (Plates I - VI).

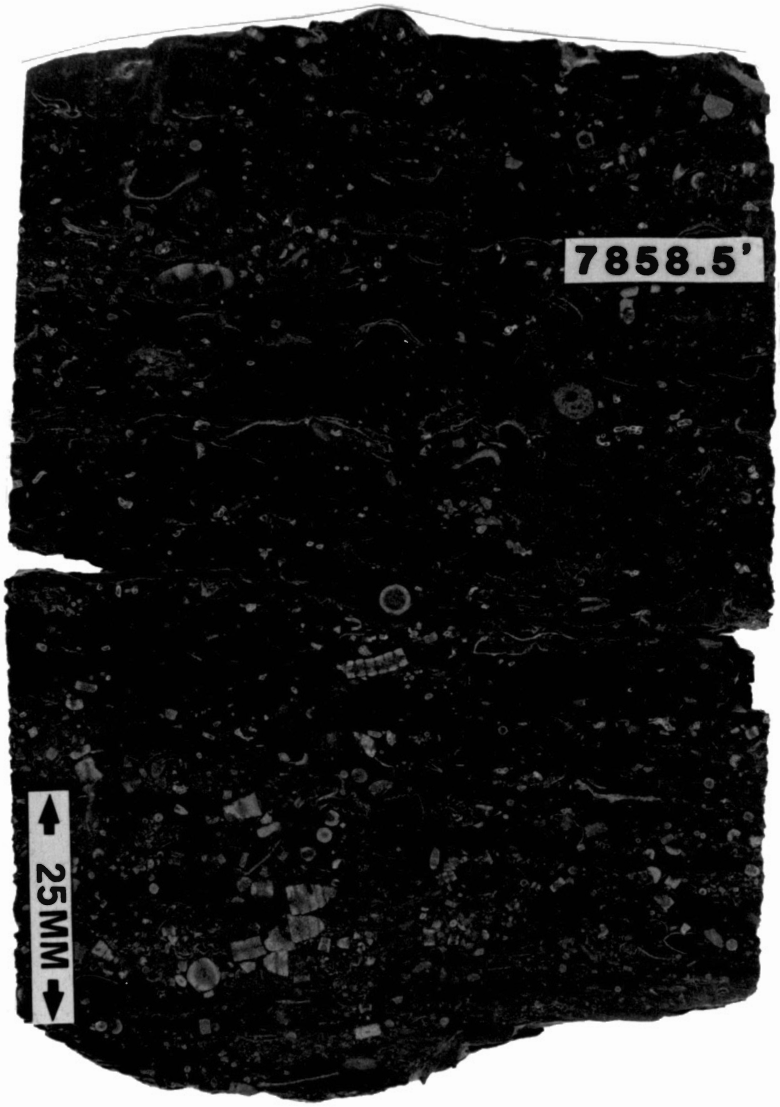

Figure 7. Haskell Limestone in Shale Facies. Fossils Include Brachiopods, Crinoids, and Microfossils (Farris Unit # 2-2).

Within this zone correlations of individual sandstone bodies are somewhat difficult primarily owing to rapid thickness changes. Thinner sandstones above this zone show greater lateral persistency. The thickest sandstone bodies in the Tonkawa occur in the western portions of the study area. Thinner, poorly developed sandstones occur in the southeast, reflecting the limits of distribution of the Tonkawa in the study area.

Areal variations in interval and net-sandstone thickness are portrayed by isopach maps (Plates VIII and IX). Tonkawa Interval thickness increase is generally to the south-southeast, except for an area from township 18 north, ranges 17 and 18 west, to township 16 north, range 18 west, which displays south-southwest thickening. The average rate of interval thickening is less than 10 feet per mile.

The approximate limits of Tonkawa Sandstone distribution is evident on Plate IX. Excluding one linear trend in township 16 north, ranges 16 and 17 west, net-sandstone thicknesses rarely exceed 10 feet in the southeastern portions of the study area.

CHAPTER V

GEOMETRY OF TONKAWA SANDSTONE

The Tonkawa Sandstones are probably highly mutilateral and to a lesser extent multistoried (Plates I - VI). As previously mentioned, the thickest sandstone bodies occur within a zone which is between approximately 70 and 150 feet below the Haskell Marker across the study area. Net-sandstone trends largely reflect sandstone bodies within this relatively thin zone. Sandstones occuring above this zone rarely exceed 5 feet in thickness for single sandstone bodies and usually contibuted less than 7 feet to the total thickness of net-sandstone.

Trends and Widths

The Tonkawa Sandstone displays dominant northeast to southwest trends (Plate IX). These trends vary in width from less than a mile to approximately four miles wide. Sheet-like net-sandstone geometries are developed in the extreme northwestern portions of the study area and in township 16 north, ranges 19 and 20 west, in the southwestern portions. Individual trends merge or coalesce locally. Bifurcating distribution patterns are also present.

Thickness

Net-sandstone thicknesses are usually less than 45 feet (Plate IX). The range is from 0 to 56 feet. Maximum single sandstone bodies rarely exceed 35 feet in thickness (Plates I - VI).

Boundaries

The Tonkawa Sandstone appears to be an elongate, lenticular, and multilateral complex. Gradational basal contacts of sandstone are dominant at the base of the Tonkawa (Plates I - VI). Sharp basal contacts are more abundant in the eastern portions of the study area. Based on net-sandstone thickness, both sharp and gradational lateral contacts occur (Plate IX).

CHAPTER VI

INTERNAL FEATURES

All cores examined in this study contained the sequence of thicker sandstones approximately 70 to 150 feet below the Haskell Marker. Composite photographs of two cores displaying sandstone bodies which may be considered characteristic of the types observed are included (Fig. 8 - 11).

Sedimentary Structures

The common sedimentary structures in the Tonkawa Sandstone cores, in approximate order of decreasing abundance are: 1) interstratification of sandstone and shale; 2) horizontal laminations; 3) small and medium-scale cross-bedding; 4) flowage or soft-sediment deformation features; 5) massive bedding; 6) initial dip or inclined bedding; and 7) burrows. Intraformational clasts are also common in the Tonkawa.

Interstratification of sandstone and shale is common in the Tonkawa (Fig. 12). Interstratification is most abundant in predominantly shaly intervals but also occurs within sandstone intervals. Within these sequences the beds of sandstone and shale commonly exhibit sharp upper

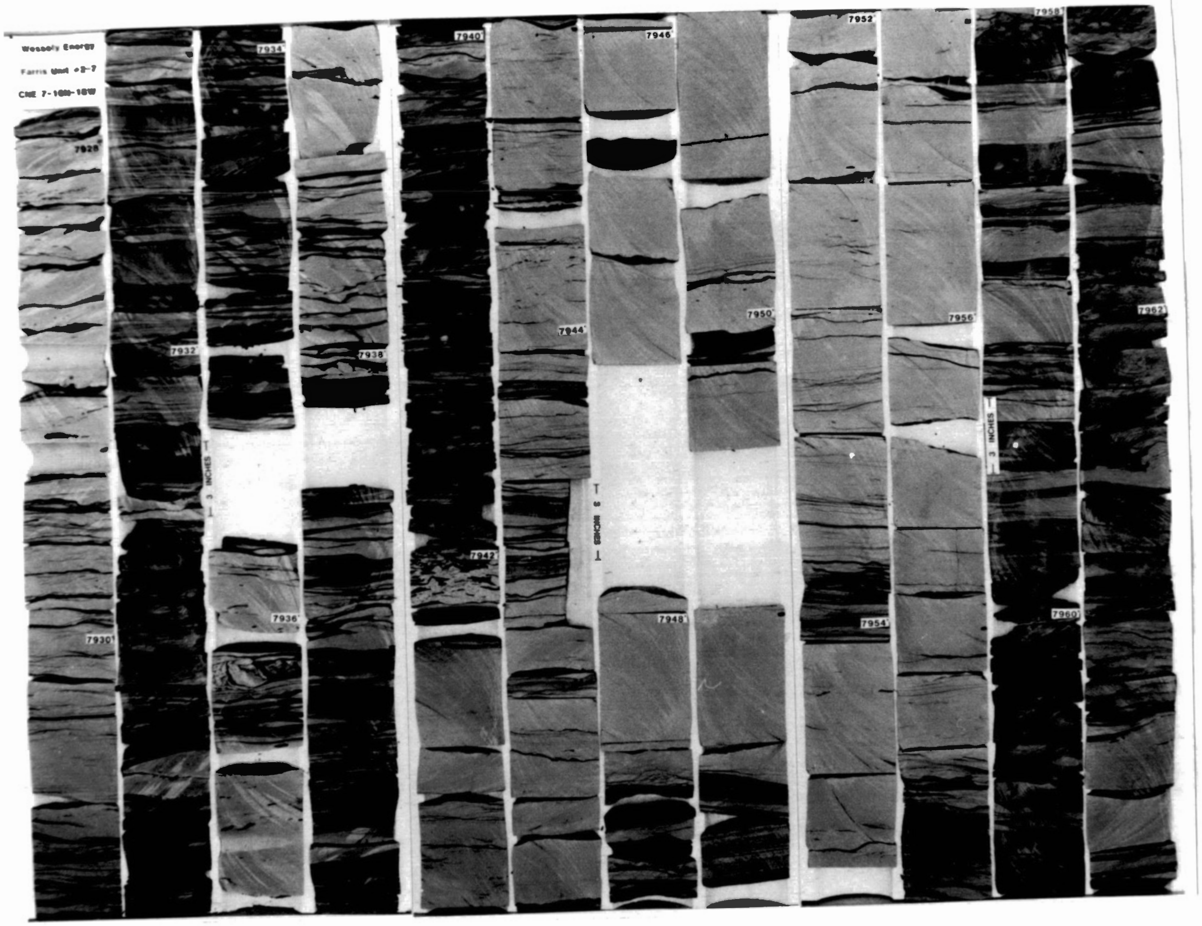

Figure 8. Upper Portion of Farris Unit # 2-7.

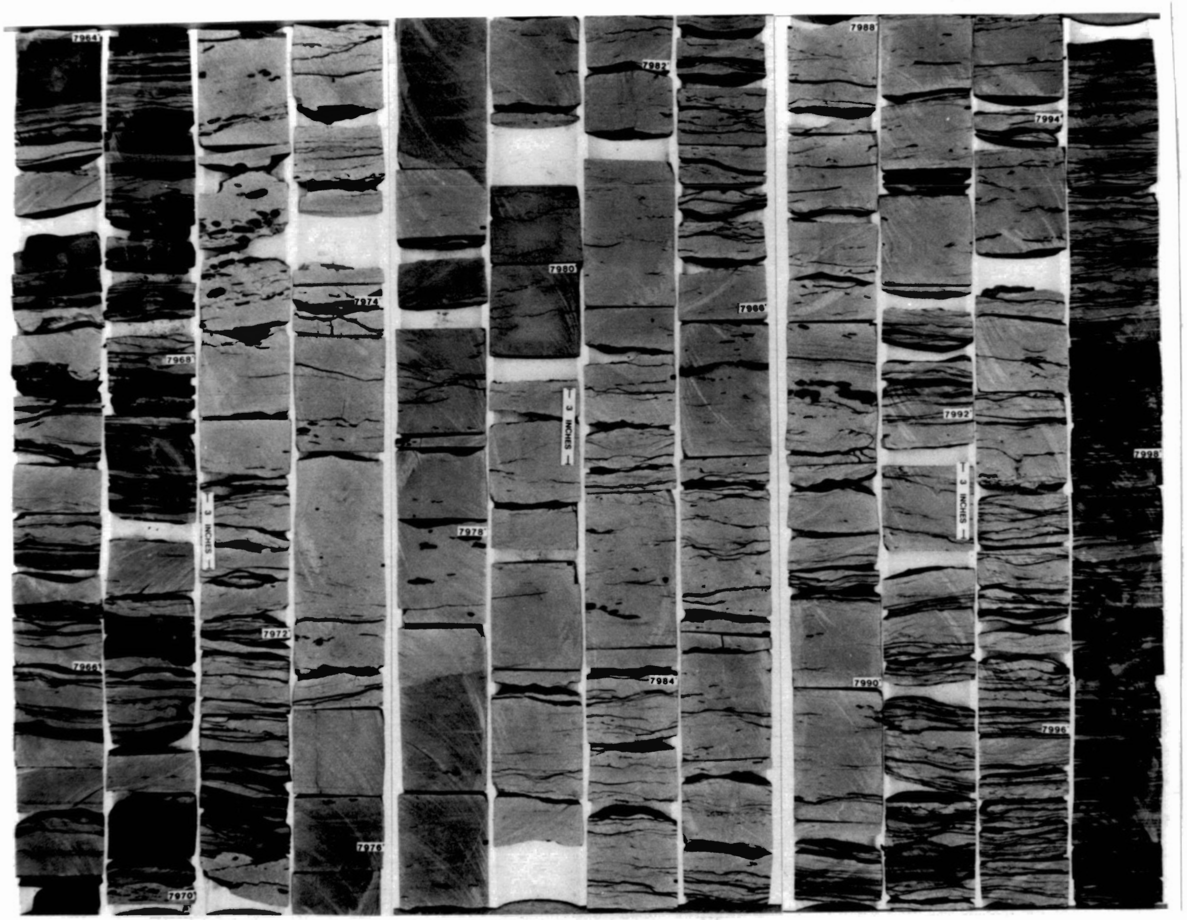

Figure 9. Lower Portion of Farris Unit # 2-7.

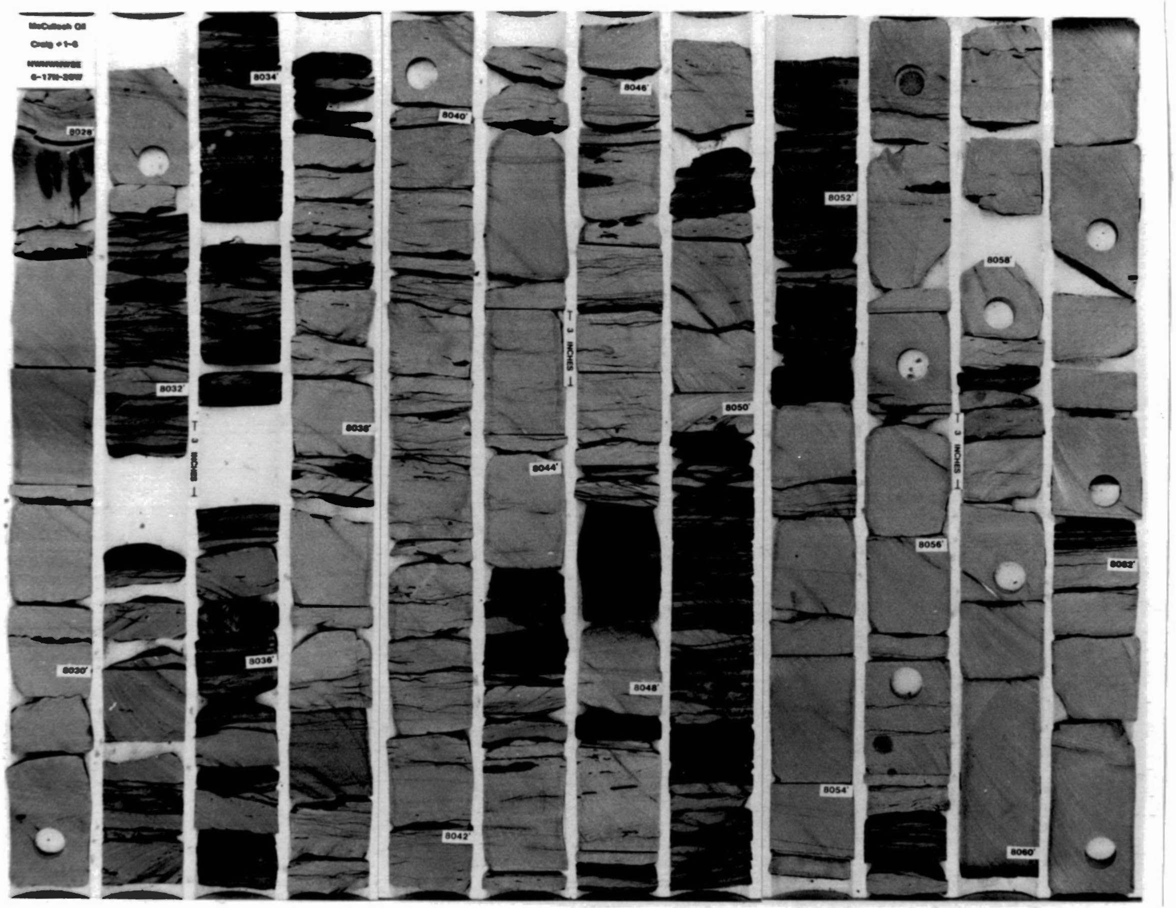

Figure 10. Upper Portion of Craig # 1-6.

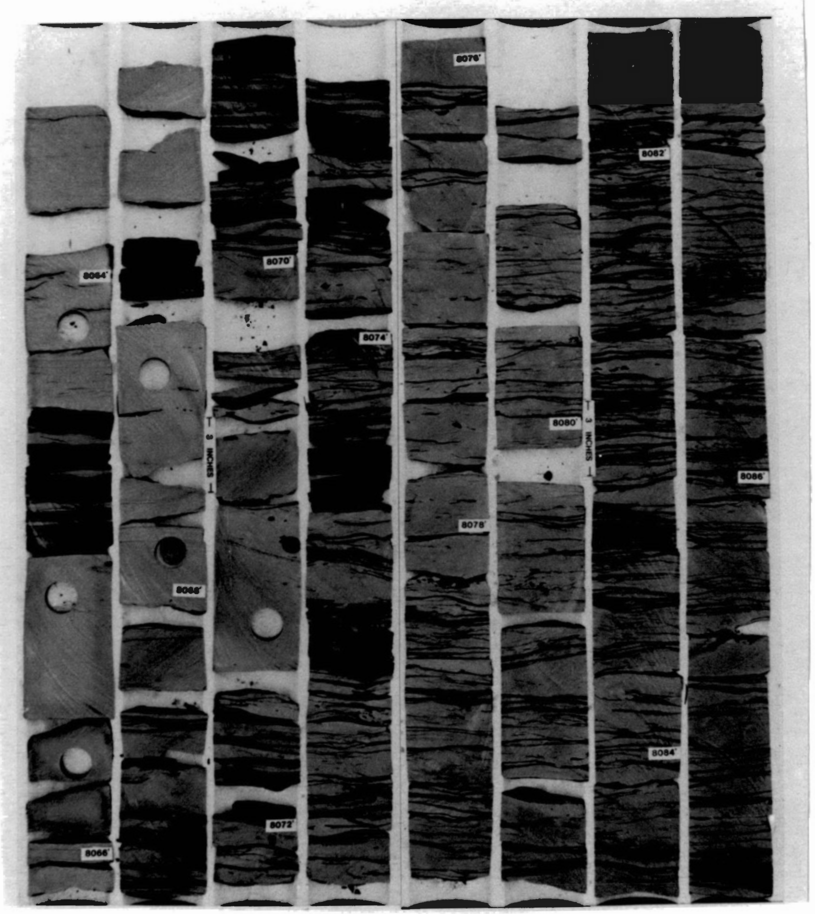

Figure 11. Lower Portion of Craig # 1-6.

Figure 12. Interstratification of Sandstone and Shale with Burrow (Craig # 1-6).

and lower contacts. Isolated burrows, small-scale cross-bedding, flowage structures, lenticular laminations, and climbing ripples all occur within these sequences.

Horizontal laminations are most abundant in interstratified sandstone and shale sequences. Horizontally laminated sandstones also occur in the Tonkawa.

Small-scale cross-bedded sandstones are very common in the Tonkawa (Fig. 13). Medium-scale cross-bedded sandstones also occur but are less abundant.

Soft-sediment deformation structures are generally restricted to the interstratified sandstone and shale sequences. Most of this is the result of flowage and is present as irregular laminae and flame structures (Fig. 14). Ball and pillow structures also occur in the Tonkawa. Slump produced soft-sediment deformation structures are also present (Fig. 15). Microfaulting of sandstone was observed rarely.

Massively bedded sandstones are common in the Tonkawa. Massive bedding is generally restricted to sandstone. The shales in the Tonkawa are usually laminated and silty. Thin, massive, organic rich shales occur only locally.

Initial dip or inclined bedding is present in sandstone (Fig. 16). This structure probably represents medium to large-scale cross-bedding. Most of the interstratified sandstone and shale sequences in the Tonkawa are effectively "horizontal".

Figure 13. Small-scale Cross-Bedding (Craig # 1-6).

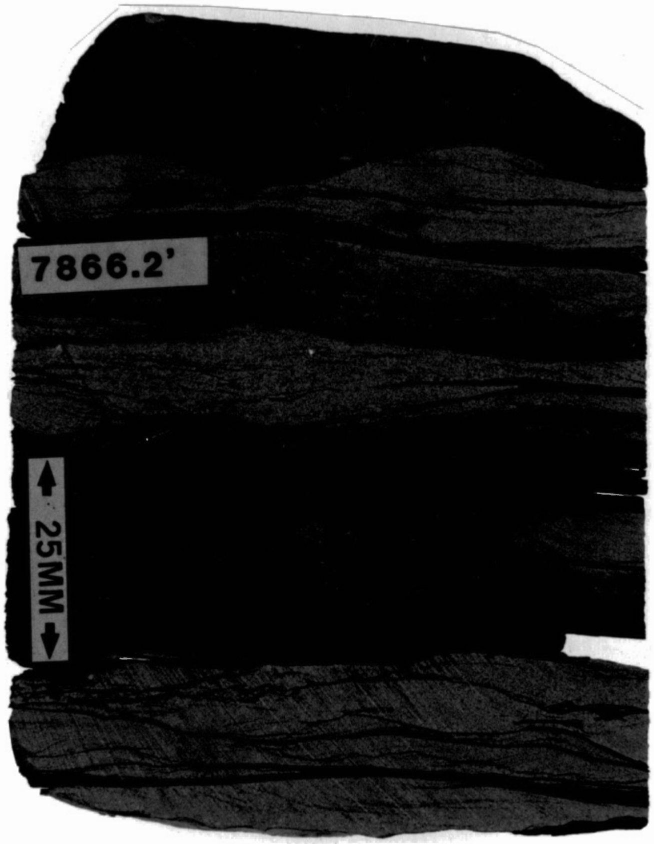

Figure 14. Soft-Sediment Deformation Structures and Carbonaceous Material Along Bedding Planes (Ellington # 1-35).

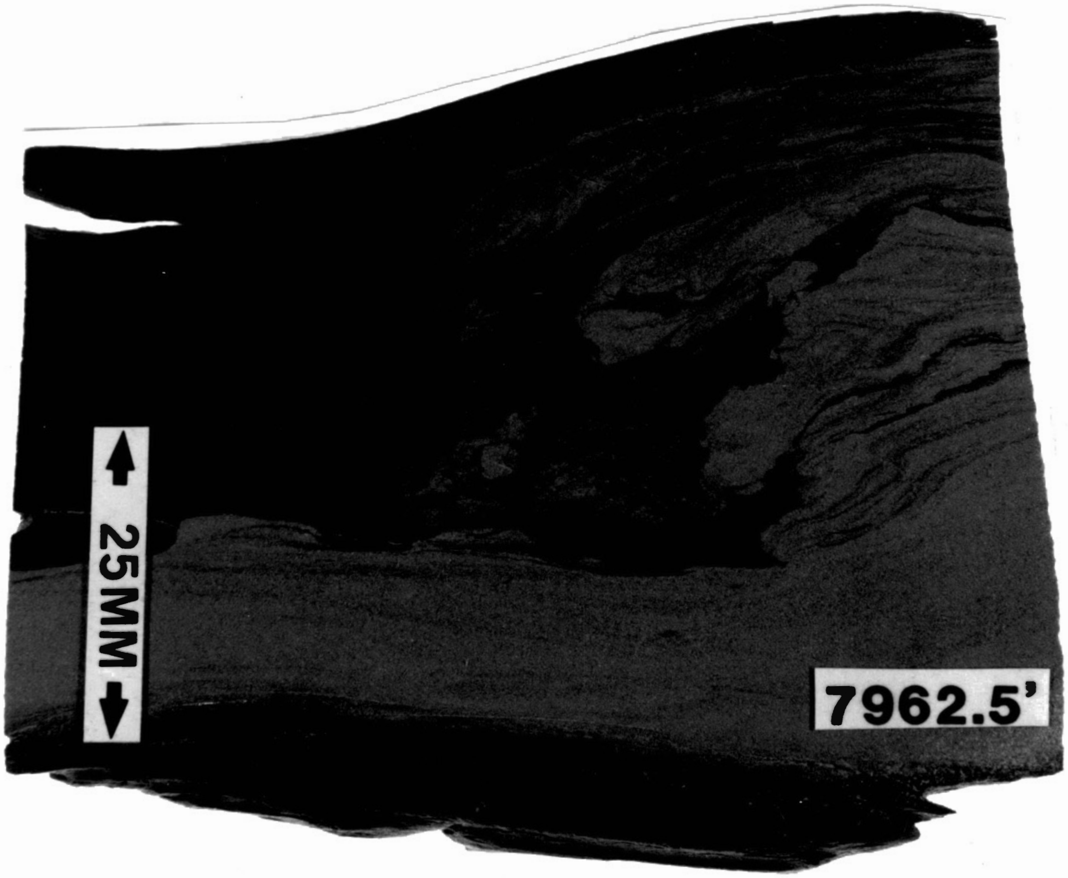

Figure 15. Slump Produced Soft-Sediment Deformation Structure (Farris Unit # 2-7).

upside down?

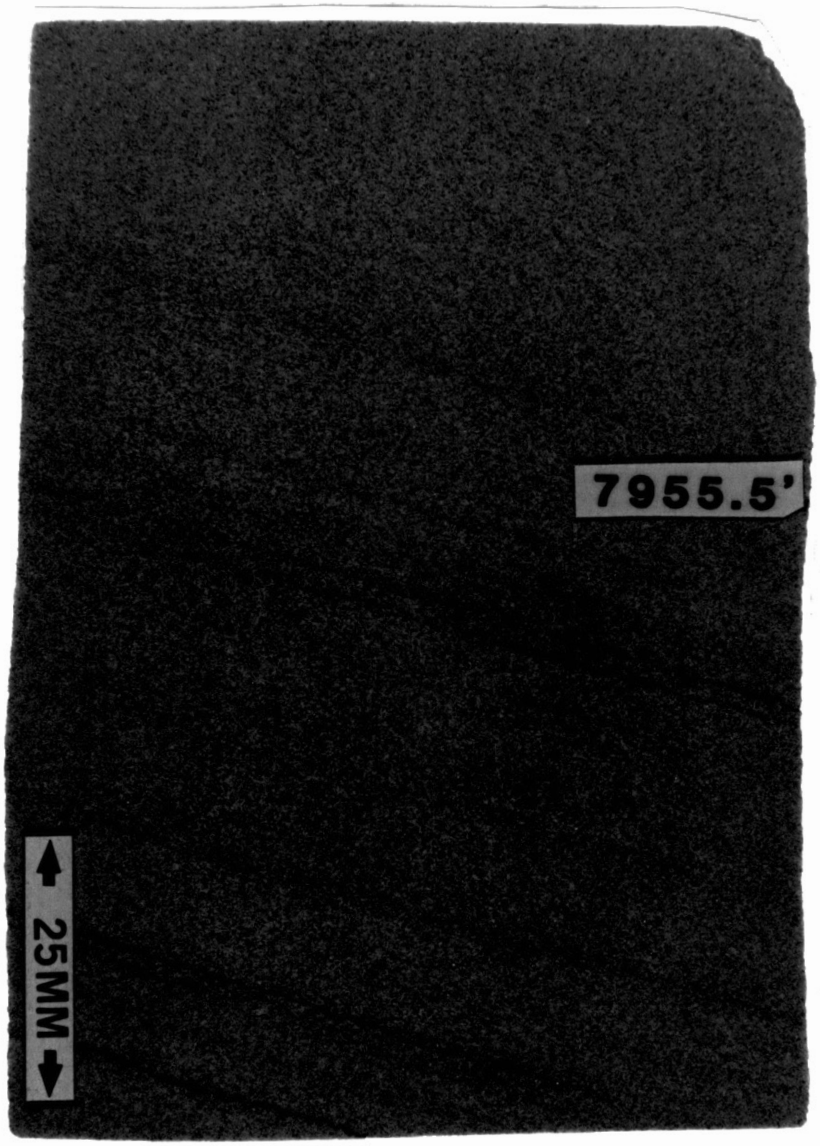

Figure 16. Inclined Bedding, Probably Medium-Scale Cross-Bedding (Craig # 1-6).

Burrowing is rare in the Tonkawa cores. Most burrowing occurs within the interstratified sandstone and shale sequences (Fig. 12). Burrows within small-scale cross-bedded sandstones were observed locally. Distinct highly bioturbated beds are absent in the cores studied.

Intraformational clasts of clay and silt-sized material are common in sandstone. These are present as a channel-lag deposit in one sample (Fig. 17). Most of the intraformational clasts appear to be "ripped-up" and redeposited clayey layers (Fig. 18). Well formed "clay-drapes" displaying slightly undulatory basal surfaces and horizontal upper surfaces also occur (Fig. 18). Commonly, the intraformational clasts and "clay-drapes" are composed of siderite.

Textures

Excluding the clay sized fraction and the intraformational clasts, the range in grain size of sandstone is from coarse silt to fine sand. The dominant grain size is very fine sand. Inconsistent vertical variations in grain size characterizes the Tonkawa Sandstone. Sharp, possibly erosive contacts are present, as well as distinct coarsening upward beds (Fig. 19). Both fining upward and coarsening upward sandstone bodies were observed.

The Tonkawa Sandstones are moderately to well-sorted, and subangular to subrounded. Detrital matrix content of

Figure 17. Channel-Lag Deposit
(Farris Unit
2-7).

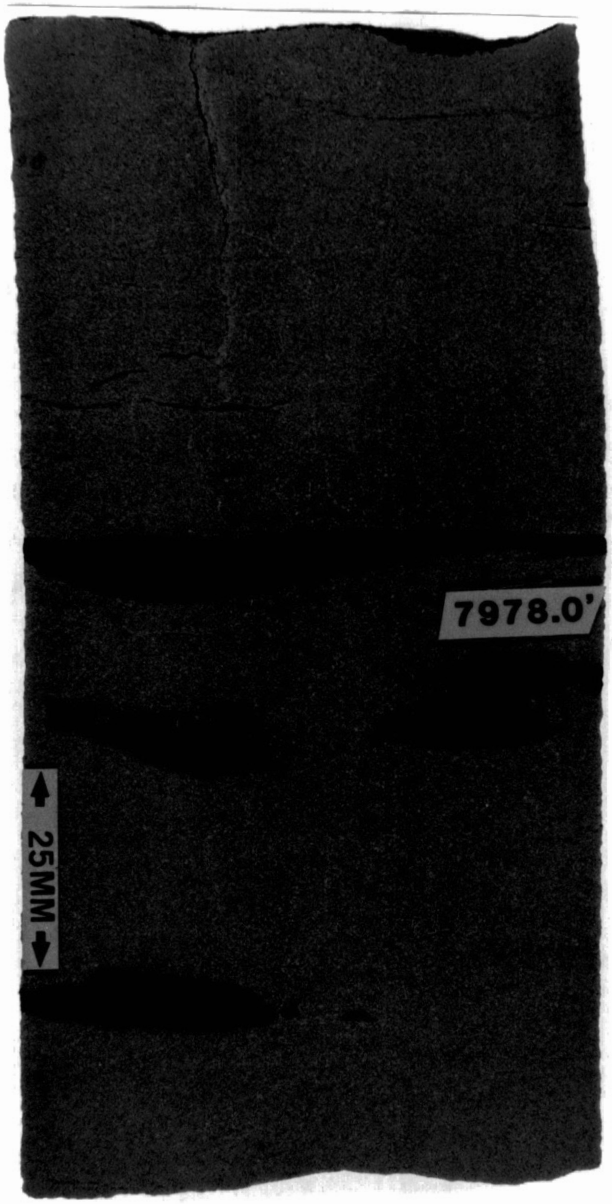

Figure 18. Intraformational Clasts and "Clay-Drape" (Farris Unit # 2-7).

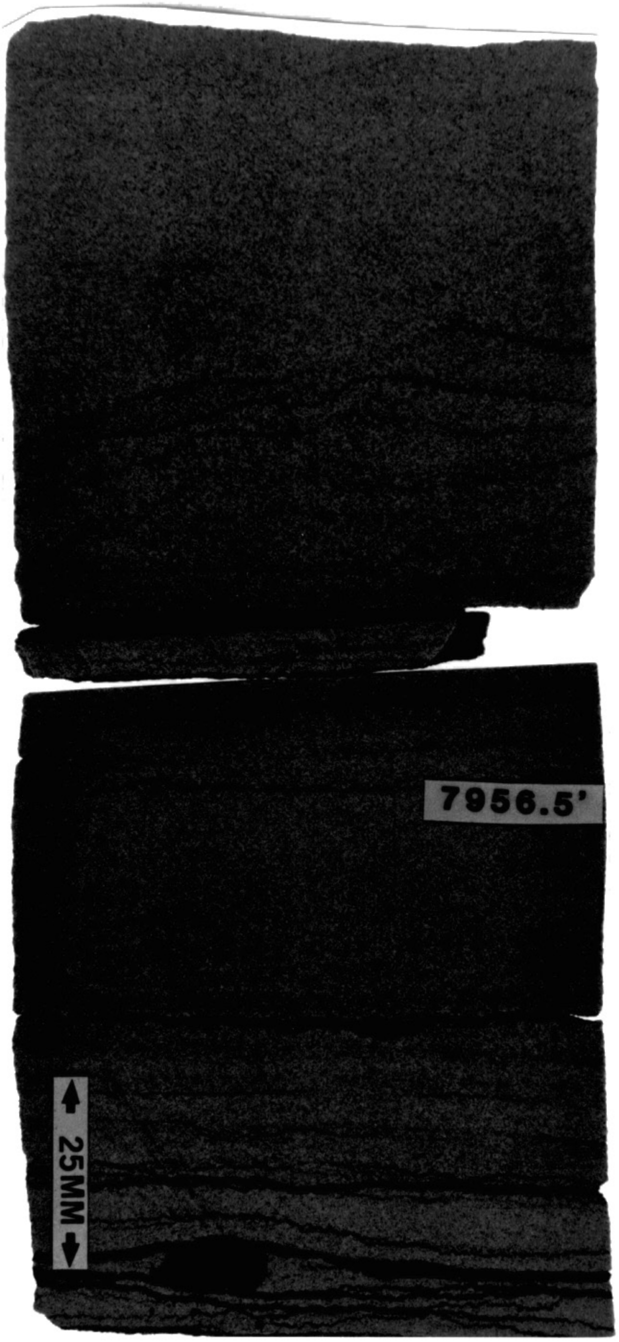

Figure 19. Coarsening Upward Sandstone Bed. Possible Micro-fault in Upper Part. Clay Clasts and Small Coal Chip in Lower Part (Farris Unit # 2-2).

the samples is usually less than 2 percent. Texturally, the Tonkawa classifies as mature (Folk, 1968).

Constituents

Carbonaceous material is common in the Tonkawa. Most of this occurs as plant material concentrated along bedding planes within interstratified sandstone and shale sequences (Fig. 14). Carbonaceous material locally occurs within interlaminated sandstone and siltstone intervals (Fig. 20). Carbonaceous material is also recognizable in thin-section where, in association with muscovite, heavy minerals, and detrital matrix, it sometimes outlines small-scale cross-bedding.

Fossil fragments are identifiable in thin-section and include a dominance of brachiopod shells and echinoderm spines and plates. The highest concentrations of fossil fragments occured in samples from the Farris Unit # 2 - 7 core at 7989 and 7970.5 feet (see Fig. 9). These samples contain up to 3 percent fossil fragments. Concentrations of fossil fragments up to 1 percent occurs in a few additional samples. Fossil fragments in other samples are absent or occur only in trace amounts. Obviously much of the fossil constituents have been transported and redeposited as their highest concentrations were found in conglomeratic beds.

An overall upward decrease in concentrations of fossil fragments was noted in each core sampled. Samples taken

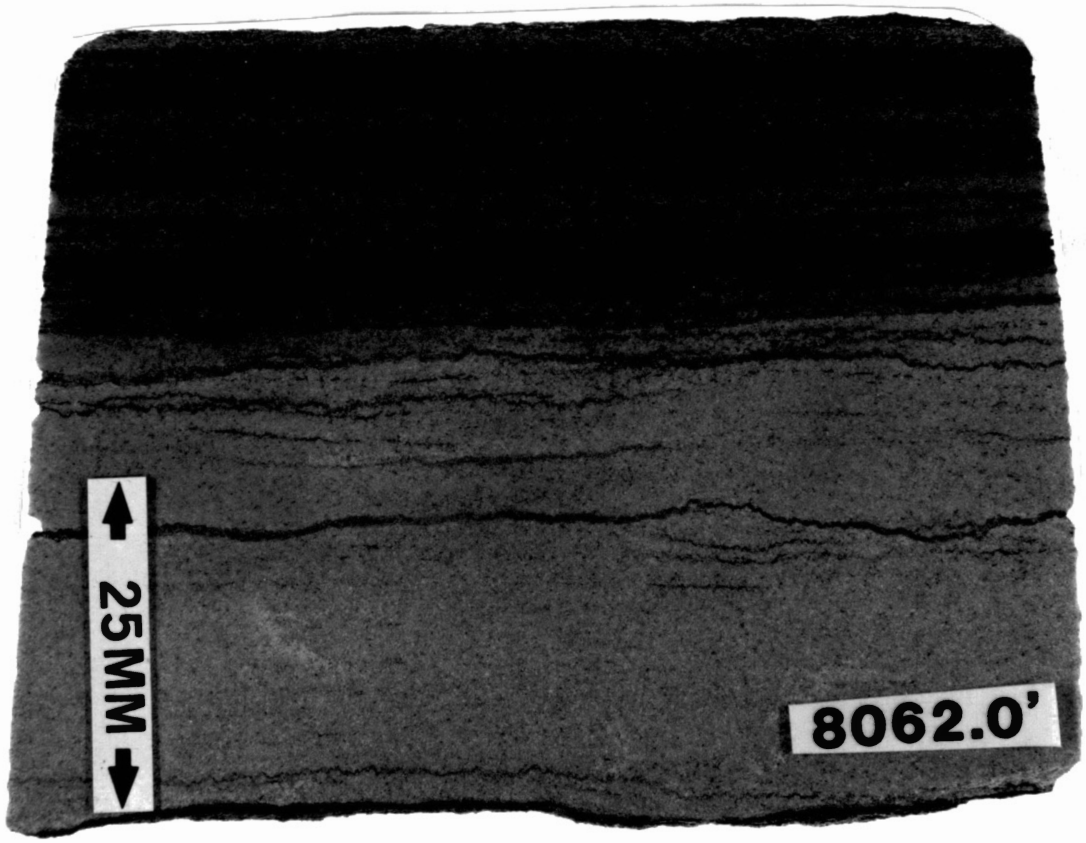

Figure 20. Carbonaceous Material Interlaminated with Silt-sized Detritus (Craig # 1-6).

from the upper portions of the cores were generally devoid of fossil fragments. Shell-debris layers or macroscopically visible shells are absent in the Tonkawa Sandstone cores studied.

Glauconite occurs in trace amounts in several samples. Trace amounts of fossil grain coatings, tentatively identified as oolitic, occur in a few samples. Similar coatings were very rarely observed on quartz grains which suggests an oolitic origin. The sparsity of the coatings and extensive diagenesis hampers attempts for an accurate identification.

CHAPTER VII

DEPOSITIONAL ENVIRONMENT

The areal distribution of net-sandstone in conjuction with the vertical and lateral positions of sandstone bodies suggests that sandstones are present mainly as distinct to coalescing lobes within the study area. These lobes are mostly elongate and are probably lenticular in form. The gamma ray and resistivity log patterns are usually highly digitate and there is a tendency to show an overall "funnel-shaped" character with respect to the shales below the Tonkawa. This pattern is evidence suggesting an absence of deep erosive channeling characteristics across most of the area. The configuration of sandstone in cross-section is somewhat similar to "delta-front" sandstones of mid-continent lobate deltas as described by Brown (1979).

The Tonkawa Sandstones remain persistently within 150 feet below the Haskell Marker in the study area. Although the Haskell Limestone is discontinuos, it may be locally oolitic in portions of the study area (Slate, 1962). Fossils observed in the Haskell show no evidence of having undergone significant transport as would be expected in a slope or deep marine setting (see Fig. 7). Published isopach maps of the interval containing the Tonkawa

Sandstones, as well as stratigraphic intervals above and below, show no developments of a well-defined "hinge-line" near the study area (Gibbons, 1962). This evidence suggests that no shelf to basin transition existed near the study area within the Tonkawa Interval.

The abundance of intraformational clasts is suggestive of strong flow and erosive conditions. Soft-sediment deformation structures imply loading, flowage, slumping, and possibly diapirism effects, which are probably the result of rapid deposition and instability. Burrows are present throughout the Tonkawa but are not abundant through any particular zone. These are characteristics considered unlike that of shallow marine offshore bar or barrier bar environments.

The presence of glauconite in trace amounts and the presence of fossil fragments in low amounts is interpreted as a partial marine influence. The tendency for fossil fragment concentrations to decrease upward may be environmentally significant, suggesting a progradation of more non-marine environments or an overall regressive episode. The abundance of carbonaceous debris strongly suggests a nearby source of plant material.

The uniform grain size of the Tonkawa is not considered definitive as an environmental indicator. It is suggestive of deposition a significant distance from an elevated source, or a source with markedly uniform textural characteristics. The presence of both fining upward and coarsening upward sandstone bodies and correspondingly, both sharp and gradational lower contacts of sandstone bodies with subjacent interstratified sandstone and shale sequences, is thought to represent deposition of individual genetic sandstone units under differing environmental conditions.

Depositional Model

The Tonkawa Sandstone in the study area was deposited in a deltaic environment. Deep marine fan and slope deposition, shallow marine offshore bar environments, and barrier-bar environments all were given consideration, but these alternatives lack evidence sufficient to support their acceptance in lieu of a deltaic model. Hence, it can be considered highly probable that the basic depositional framework of the Tonkawa Sandstone in the study area is that of deltaic environments and the associated facies thereof.

In order to gain insight into the overall depositional setting of the Tonkawa as interpreted in this study it is relevant to briefly outline properties of deltaic sandstone bodies. The articles which proved most useful in this study are the synopses of deltaic environments provided by Coleman and Prior (1980, 1982). The following discussion is largely derived from their work. Following their model, specific sandstone facies thought to be present in the Tonkawa cores studied include distributary mouth bars, distributary channel fill, and interdistributary bay crevasse splays (Appendix).

Distributary mouth bars form as a result of shoaling at the seaward terminus of distributary channels. Individual distributary mouth bars tend to have a fan shape in plan view which, through coalescing of various distributary mouth bars, may form a sheet-like sandstone body. Progradation of the distributary system may result in an elongate sandstone body. Extensive progradation may result in destruction of the distributary mouth bar by fluvial processes or stacking of fluvial distributaries above distributary mouth bars (Swanson, 1980).

Deposits of distributary mouth bars display a generally coarsening upward sequence including lowermost silts and clays overlain by alternating sand and silt units and uppermost sands. Coleman and Prior (1982) term these deposits prodelta, distal bar, and distributary mouth bar, respectively. Silts and clays may occasionally be deposited with distributary mouth bar sands and be preserved in the absence of wave reworking (Kanes, 1970; Donaldson, et. al., 1970). Distally, away from the distributary, increasing amounts of silts and clays of the distal bar are deposited. As the distributary mouth bar thickens due to progradation, loading may result in deformation of the sand body and subjacent silts and clays. Bioturbation is generally confined to the lowermost portions of the deposits reflecting the lower energy levels in that environment. Concentrations of shell fragments can be very high in distributary mouth bars reflecting the marine conditions into which they are deposited (Kanes, 1970; Donaldson, et. al., 1970). Clay gall clasts may occur as a result of high flow conditions across the bar (Coleman and Gagliano, 1965).

Distributary channels are the natural flume through which a portion of the parent river system is directed to the receiving basin. Distributary channels may erode into previously deposited prodelta, ditributary mouth bar, or interdistributary bay sediments. Distributary channels display sharp, erosional bases and may contain carbonaceous material, wood fragments, and clay clasts. Through subsidence, lateral migration, or slow abandonment the channel may fill with sand. Sudden abandonment of the distributary may result in filling of the channel with sands, silts, and clays displaying extremely sharp bedding contacts and abundant slumping due to channel bank failure.

Crevasse splay deposits build into shallow bays adjacent to distributaries. Processes forming crevasse splay sandstones are somewhat similar to processes forming distributary mouth bars, except on a much smaller scale allowing for the shallower water into which they prograde (Elliot, 1974). Sandstones of these deposits commonly display a coarsening upward sequence, but fining upward sequences can occur. The lenticular nature of bedding in shale sequences, abundant burrowing, and abundant carbonaceous material along bedding planes are characteristics of interdistibutary bay fill deposits (Coleman, 1981).

Coarsening upward sandstone bodies generally displaying gradational contacts with interstratified sandstone and shale sequences below and containing fossil fragments and burrows are interpreted as distributary mouth bars. These sandstones are the most abundant in the cores studied. The "funnel-shaped" well-log signature patterns common to ancient "delta-front" sandstones (Brown, 1979) across much of the study area implies that these sandstones are the most abundant within the study area.

Sandstone bodies generally displaying sharp contacts with interstratified sandstone and shale sequences below, containing abundant carbonaceous material, lacking burrows, and containing only traces of shell fragments may represent distributary channel fill deposits. These are not present in each core studied. In the Craig # 1 - 6 core the sandstones are stacked, a condition which is not apparent in the other cores which contained similar sandstones.

Sandstones thought to represent crevasse splay deposits are also lacking in each core. Generally, abundant burrowing, abundant carbonaceous material, fossil fragments in trace amounts, and association with lenticular nature of shales above and below were used to distinguish the presence of these deposits. These sandstones are very thin where present, usually less than 3 feet thick.

The greater abundance of coarsening upward sandstone bodies in the cores studied and the "funnel-shaped" well-log patterns across much of the study area suggests that deposition in the study area is recorded dominantly by "delta-front" sandstones. Sandstones which may be distributary channel fill deposits and crevassse splays in the cores suggests "lower delta plain" deposition and are interpreted as representing a progradation of environments during regression.

The Farris # 2 - 2 core contains the thinner sandstones above the main development of sandstone in the Tonkawa. These sandstones display intraformational clasts, horizontal laminations, massive bedding, small-scale cross-bedding, and burrows. They may represent the extreme distal portions of a second delta lobe. The Haskell Limestone may record open-marine, shallow water conditions and a transgressive episode.

The dominant trends in a northeast to southwest direction implies sediment transport from the northeast. The Tonganoxie ("Stalnaker") Sandstone of eastern Kansas also displays dominant northeast to southwest trends (Lins, 1950; Winchell, 1957; Sanders, 1959; Griffith, 1981). These authors describe the Tonganoxie as a very fine and fine grained, micaceous sandstone. The Tonganoxie records deposition in fluvial environments. These authors believe the source area was located to the northeast of the mid-continent region. Both the Tonkawa and the Tonganoxie are persistently located close below the Haskell Limestone (Lukert, 1949). Recently, Walton and Griffith (1985) described the Tonagnoxie in extreme southern Kansas as a fluvial-deltaic complex. Based on the ease of the correlation and the persistent location close below the Haskell Limestone, and also on similar lithologies and trends, the Tonkawa Sandstone of this study is believed to be a southwestern extension of the Tonganoxie Sandstone.

CHAPTER VIII

PETROLOGY

Detrital Constituents

Each thin-section sampled from the Tonkawa Sandstone plotted as a sublitharenite on a QRF ternary diagram (Fig. 21). Table I lists the averaged percentages of detrital constituents observed in the thin-section microscopy study.

Monocrystalline quartz displaying straight to slightly undulatory extinction is the dominant grain in the fabric ranging from 49 to 72 percent of the total rock volume. Many of the quartz grains contain vacoules. Needles and microlites of mica, rutile, and other minerals are also common. Boehm lamellae in quartz was observed in several samples. Boehm lamellae may represent quartz which underwent intensive strain at the source area (Scholle, 1979). Polycrystalline quartz is present in each thin-section (Fig. 22). Polycrystalline quartz locally constitutes up to 3 percent of the rock.

Rock fragments are present from 2 to 10 percent of the total rock volume. The most abundant type is probably of low grade metamorphic origin and commonly show signs of ductile deformation due to compaction (Fig. 23). Many of the rock fragments display a parallel arrangement of

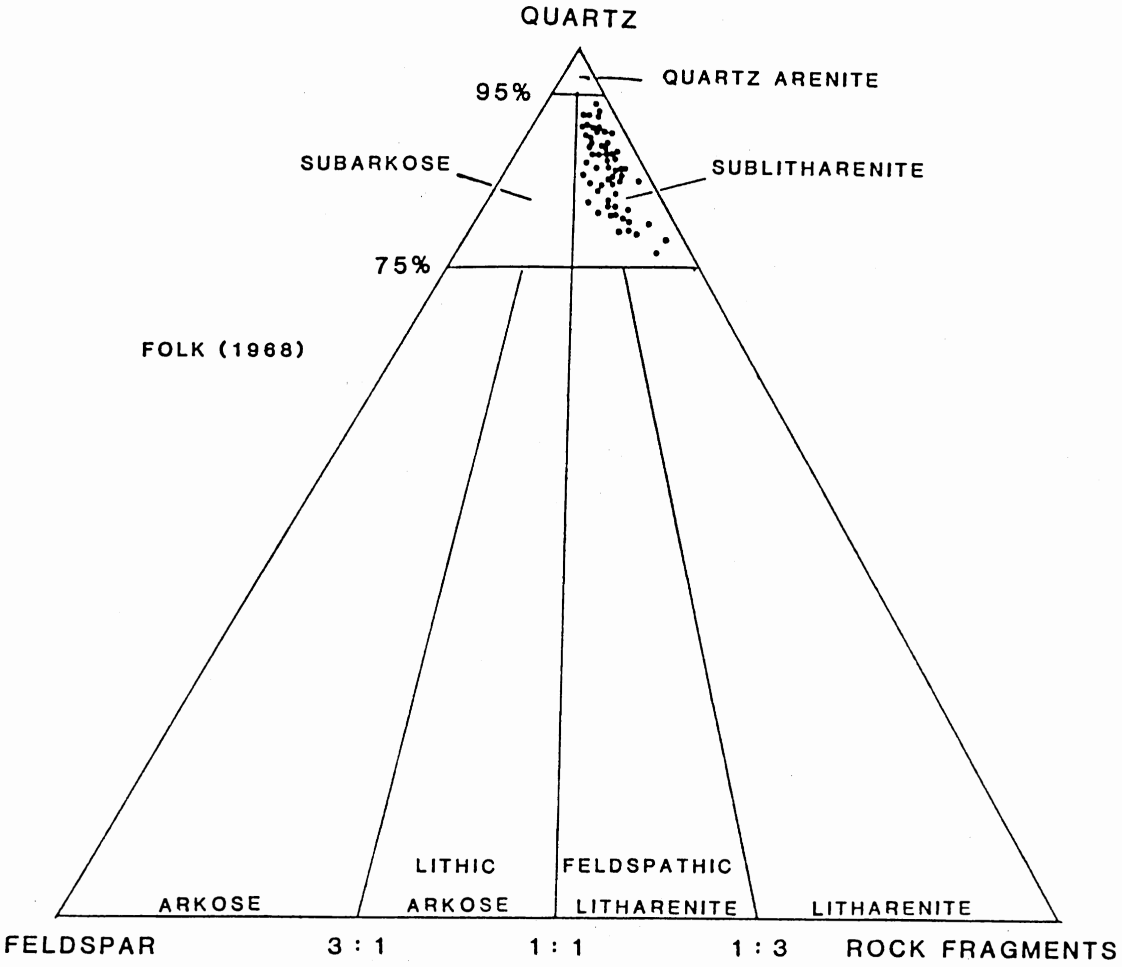

Figure 21. Classification of Tonkawa Sandstone.

TABLE I

AVERAGE DETRITAL COMPOSITION OF THE TONKAWA SANDSTONE

CONSTITUENT	AVERAGE PERCENTAGE
QUARTZ	63.0
ROCK FRAGMENTS	5.9
FELDSPARS	2.9
MUSCOVITE	2.1
BIOTITE/CHLORITE	trace
ZIRCON/TOURMALINE	trace
MATRIX	trace
GLAUCONITE	trace
FOSSIL FRAGMENTS	trace
CARBONACEOUS MATERIAL	trace

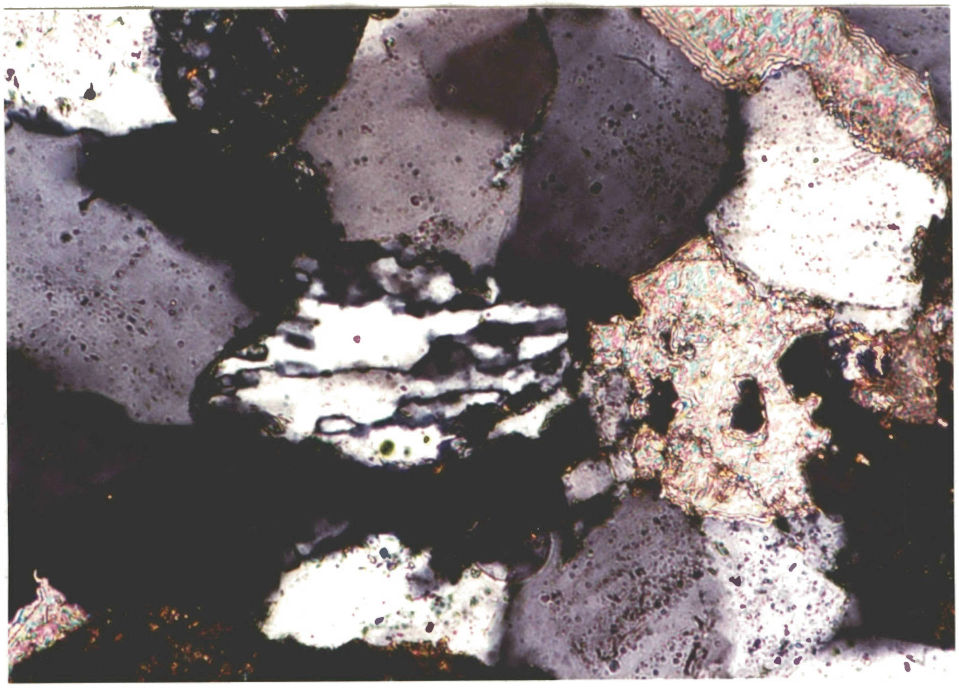

Figure 22. Polycrystalline Quartz (Farris Unit # 2-7, 7970.5', X200).

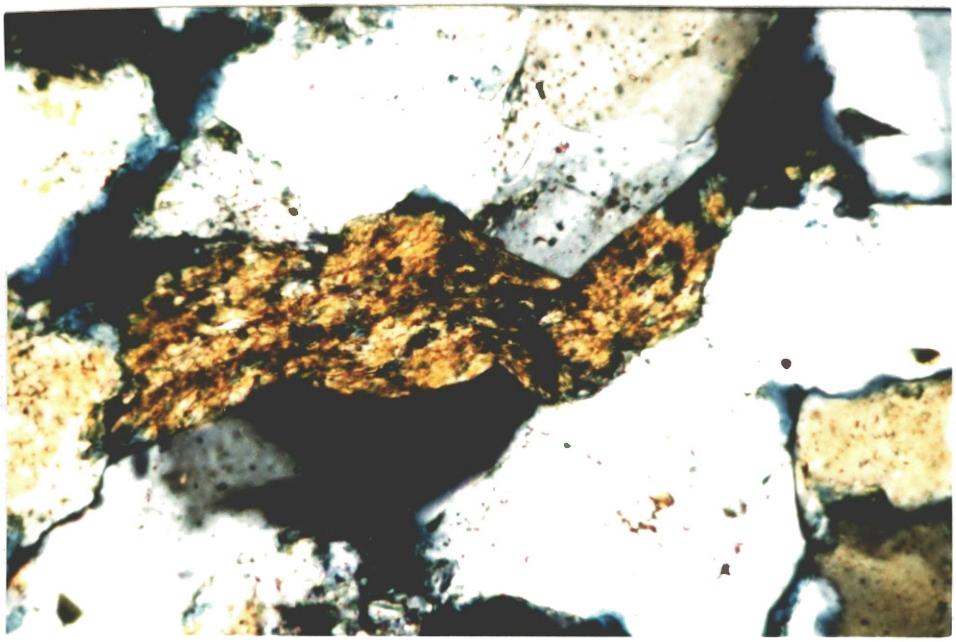

Figure 23. Rock Fragment of Probable Low-Grade Metamorphic Origin (Craig # 1-6, 8056', X200).

minerals also suggesting a metamorphic origin (Fig. 24). Shale and mudstone rock fragments of intraformational origin locally form up to 25 percent of the rock, but were generally present in trace amounts or were absent in samples taken for this study. Chert is present in trace amounts in a few thin-sections.

The relative abundance of metamorphic rock fragments observed in this study is thought to indicate a strong influence of a metamorphic source terrain. As previously mentioned, the source area for the Tonkawa Sandstone is believed to have been located to the northeast of the mid-continent (see Chapter VII). Possible metamorphic terrains which could have supplied clastics from the north and northeast include the Appalachian region or the Canadian Shield.

Feldspar content ranges from 1 to 6 percent of the rock. Plagioclase feldspars are the most abundant and display distinctive albite twinning (Fig. 25). Orthoclase feldspars are also present in trace amounts. Microcline, a potassic feldspar distinguished by "grid" or "cross-hatched" twinning, is present in very low amounts. Feldspar content of the Tonkawa may have originally been higher upon deposition as much of the porosity in the sandstones has been produced through their dissolution (see Chapter IX).

Muscovite is a very common accessory mineral in the Tonkawa with concentrations ranging from 1 to 6 percent of

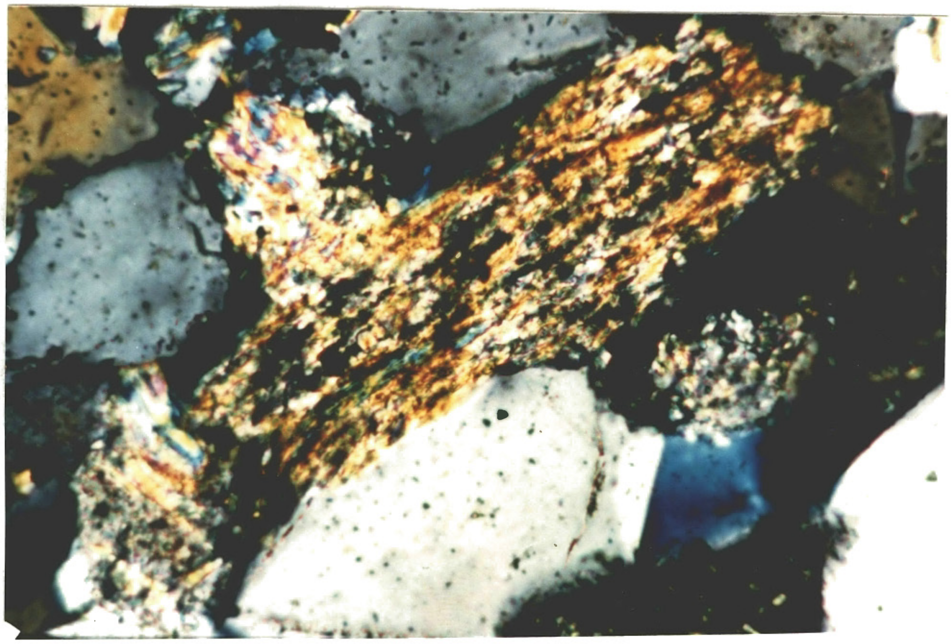

Figure 24. Rock Fragment of Probable Metamorphic Origin (Farris Unit # 2-7, 7982.5', X200).

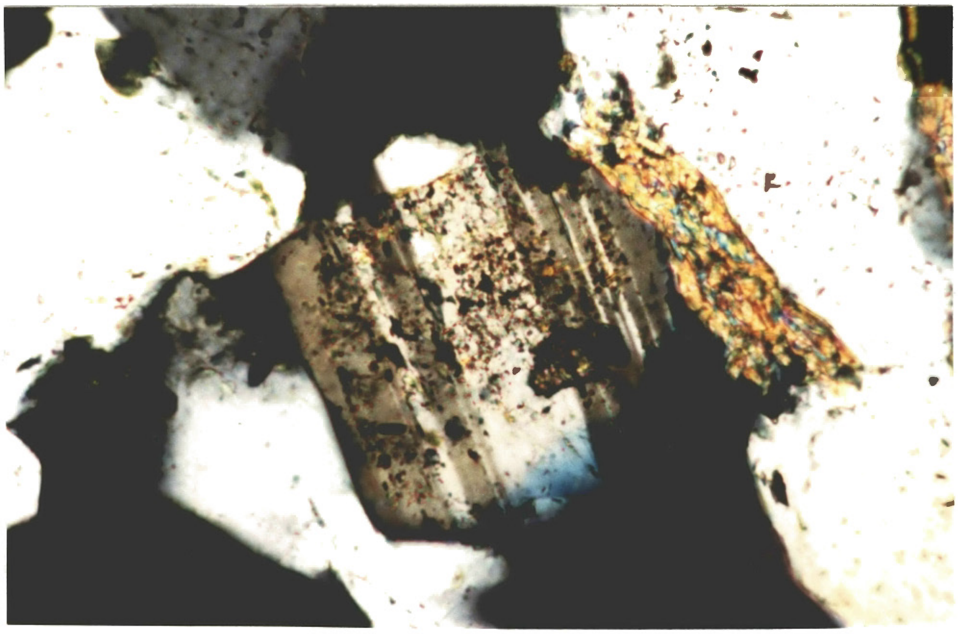

Figure 25. Plagioclase Feldspar with Overgrowth (Farris Unit # 2-2, 7954.5', X200).

the volume. Commonly, muscovite is observed as bent or broken flakes representing early compaction of the sandstone (Fig. 26). Biotite and chlorite grains are also present in trace amounts. Alteration of biotite to chlorite is common in ancient sandstones (Shelley, 1985). Therefore, the distinction between biotite and chlorite was not made in this study. Detrital biotite was observed and detrital chlorite may also be present.

Zircon is the most abundant heavy mineral in the Tonkawa and is present in all samples (Fig. 27). In several samples zircon is present up to 1/2 percent of total volume. Tourmaline is present in very low amounts.

Detrital matrix in the Tonkawa is commonly observed as "pseudo-matrix" squeezed between grains (Fig. 28). Diagenesis later transformed this material into siderite in most of the thin-sections. Accurate identification of the original composition of the matrix is hampered by this replacement.

Glauconite is present in trace amounts in most samples. Characteristically, glauconite displayed rounded to deformed, speckled, green grains. Fragments of echinoderm spines and plates, brachiopod shells and spines, as well as possible fusilinid and bryozoan fragments were observed. Reworked oolites may also be present in a few samples in trace amounts.

Carbonaceous material content ranges from 0 to 30 percent and is usually present in trace amounts in each

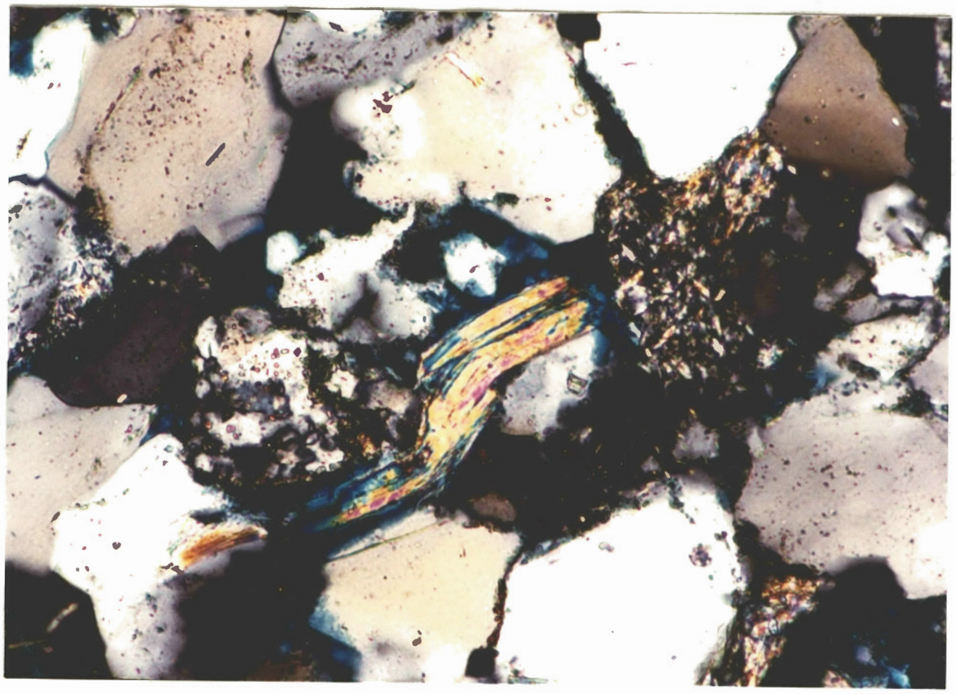

Figure 26. Muscovite Flake Bent During Early Compaction (Saylor A#1, 7954.5', X100).

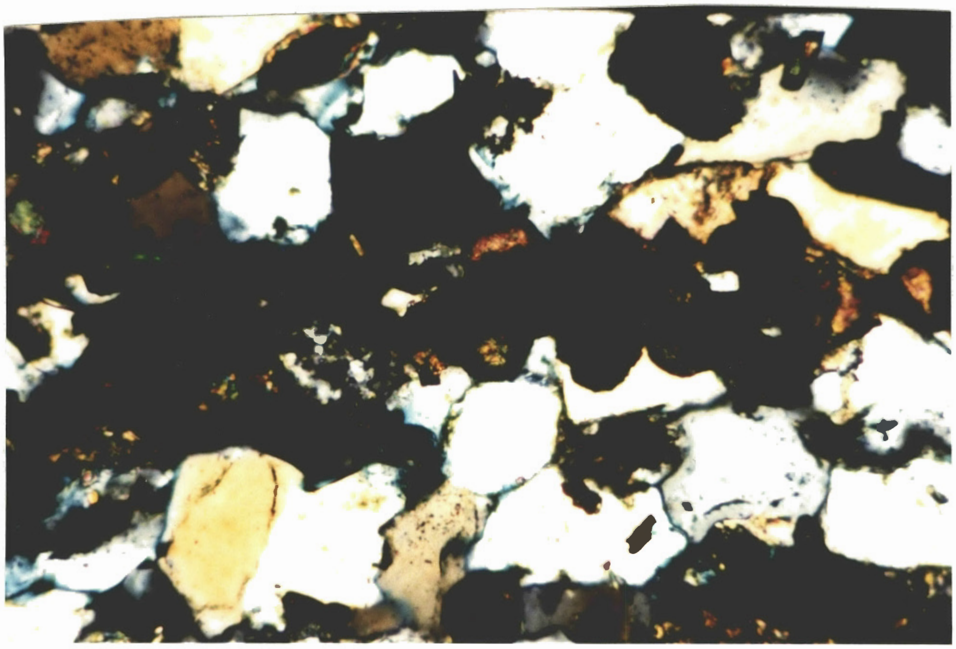

Figure 27. Zircon and Carbonaceous Material (Craig # 1-6, 8043.5', X100).

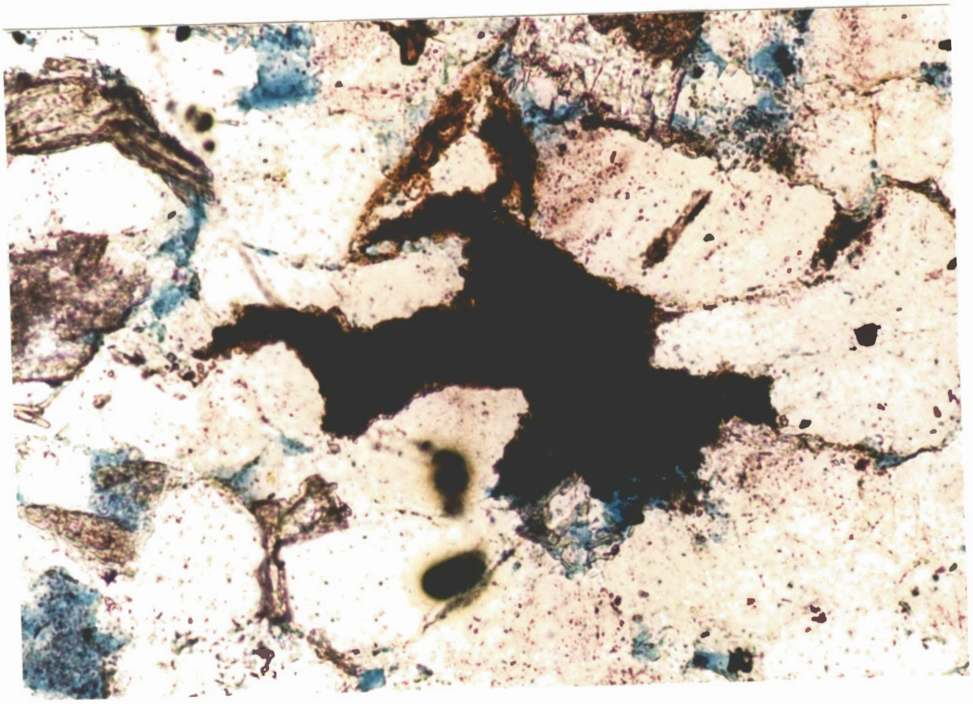

Figure 28. Pseudomatrix Material Composed of Siderite (Farris Unit # 2-7, 7975', X100).

thin-section. Very small coal chips or wood fragments were observed in a few sandstone beds.

Authigenic Constituents

Table II lists the averaged percentages of authigenic minerals in the Tonkawa Sandstone. Compositional percentages of authigenic constituents was found to be highly variable. Four minerals which locally form major cements are present and include silica, calcite, dolomite, and siderite. Where a dominant cement or cements were observed through a zone it was recorded (Appendix).

Syntaxial quartz overgrowths are present in a majority of the samples. Quartz overgrowth content ranges from 1 to 11 percent of the rock. Clay rims on detrital quartz allowed the distinction between overgrowths and grains to be made for point-counting purposes (Fig. 29).

Dolomite is present in trace amounts to 33 percent of the rock. Dolomite is usually present in amounts less than 4 percent. The high average of dolomite in Table II reflects a few samples displaying extensive dolomite cementation (Fig. 30). Dolomite as observed in thin-section is essentially identical in form to calcite, both appear as poikilotopic masses. The distinction between the two was based on X-Ray diffraction analysis. Calcite is present up to 24 percent of the rock locally, but usually occurs in trace amounts. In the Farris Unit # 2 - 7 core extensive dolomite cementation appears as a darker hue from

TABLE II

AVERAGE AUTHIGENIC COMPOSITION OF THE TONKAWA SANDSTONE

CONSTITUENT	AVERAGE PERCENTAGE
QUARTZ OVERGROWTHS	4.2
DOLOMITE	6.3
CALCITE	1.1
SIDERITE	0.5
FELDSPAR OVERGROWTHS	trace
PYRITE	trace
CHLORITE	0.9
KAOLINITE	0.8
ILLITE	trace

Figure 29. Chlorite and Quartz Overgrowths (Farris Unit # 2-7, 7956', X100).

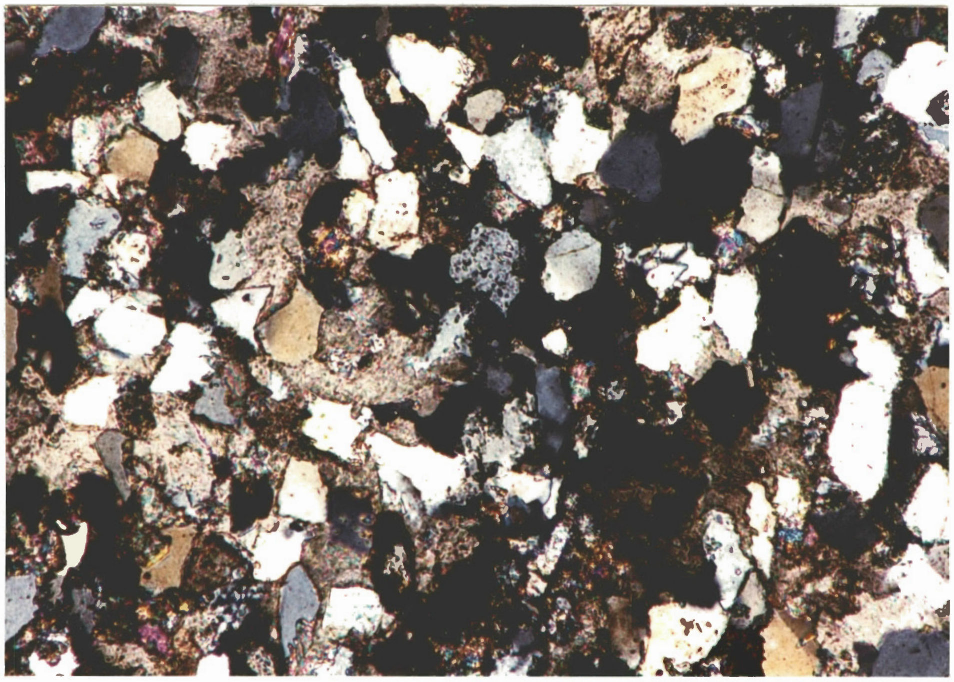

Figure 30. Dolomite Cement (Farris Unit # 2-7, 7979', X40).

approximately 7976 to 7977 and 7978.5 to 7980.5 feet. Extensive calcite cementation occurs between, from approximately 7977 to 7978.5 feet (see Fig. 9).

Siderite was noted as being associated with intraformational clasts and detrital matrix in each core except the Fancher # 1 - 17. Siderite is interpreted as a replacement of the clasts and the matrix. Siderite is also present in trace amounts in many of the thin-sections as very small, isolated, flattened rhombs. Siderite as the major cement occurs locally in the Craig # 1 - 6 core. In this core siderite content generally increases upward. Siderite as grain coatings is present up to 19 percent in one sample (Fig. 31). Bands displaying darker hues reflect siderite in the Craig # 1 - 6 core (see Fig. 10, 8028', 8029', 8047.5', 8060'; Fig. 11, 8071').

Syntaxial feldspar overgrowths were observed very rarely (Fig. 25). Overgrowths on orthoclase feldspar proved useful in distinguishing the presence of this mineral.

Pyrite is present in many of the samples in trace amounts. Locally, pyrite concentrations reached 1 percent. Cubic outline and opacity distinguishes pyrite (Fig. 32).

Chlorite is the most abundant authigenic clay mineral present (Fig. 29). Concentrations of chlorite reached 4 percent in several samples. Chlorite occurs as a pore lining and pore filling mineral and as a grain coating. Kaolinite is present as a pore filling mineral (Fig. 33).

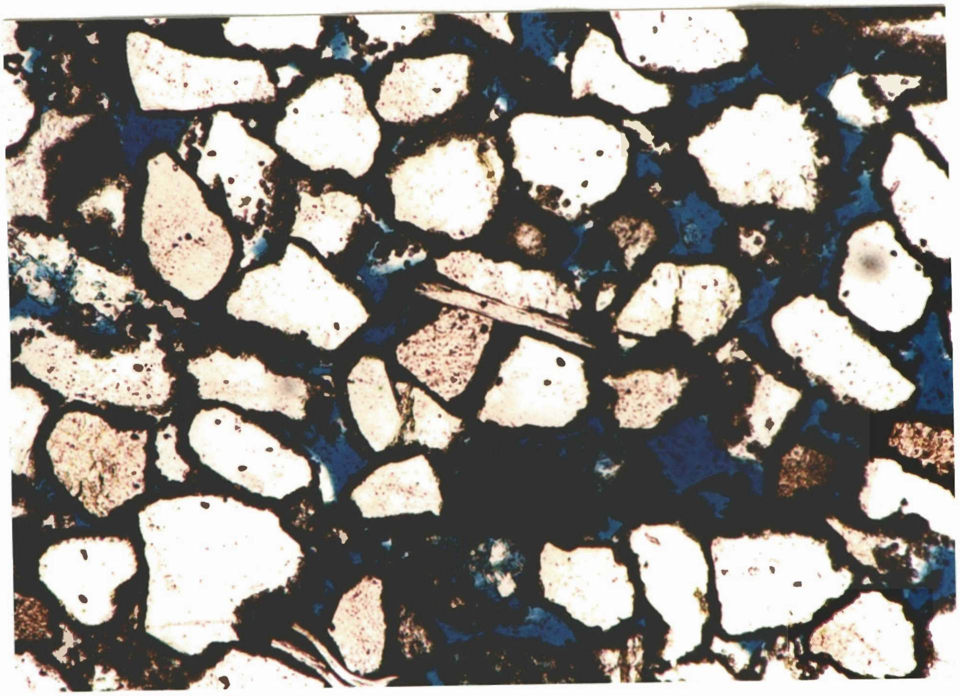

Figure 31. Siderite Cement (Craig # 1-6, 8047.5', X40).

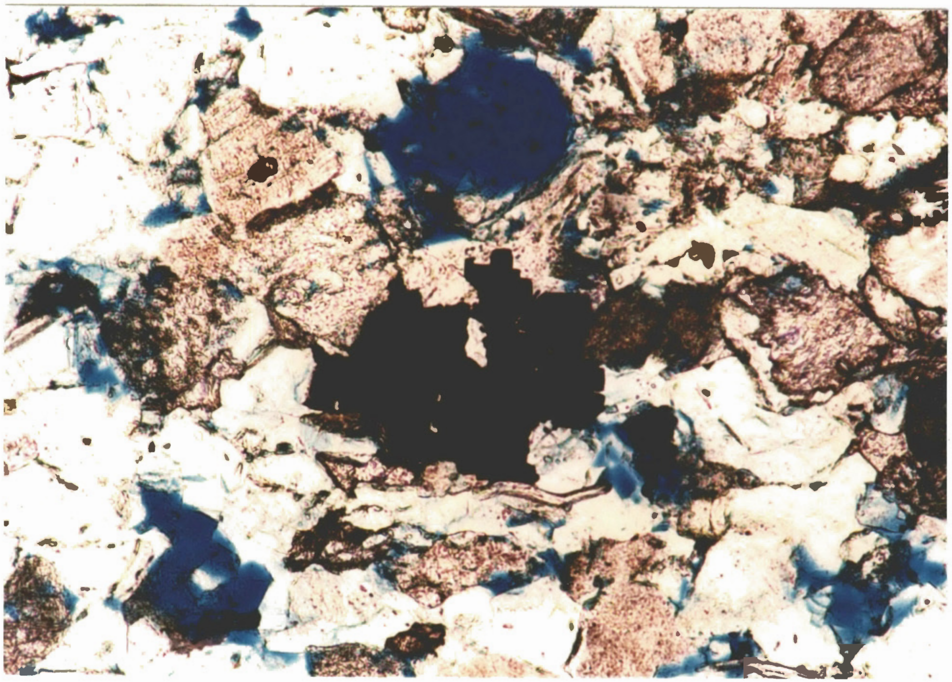

Figure 32. Pyrite (Saylor A#1, 7920.5', X40).

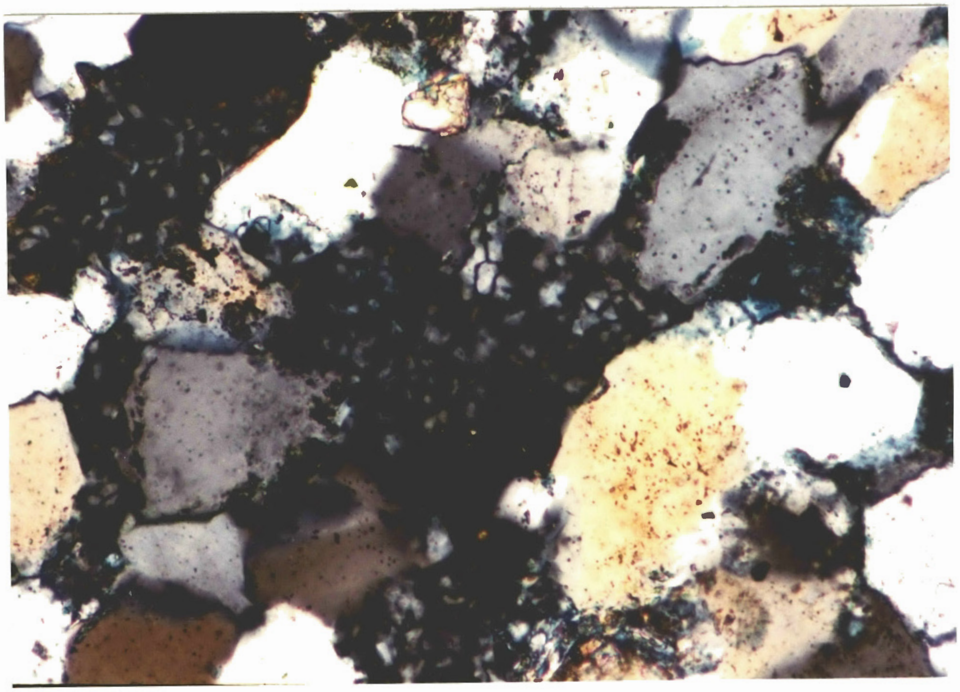

Figure 33. Kaolinite (Farris Unit # 2-7, 7975', X100).

Kaolinite concentrations ranged from 0 to 5 percent. Illite is present in trace amounts as a pore lining and pore filling mineral generally in trace amounts. Illite as revealed by X-Ray diffraction is thought to be largely detrital in origin. The peaks are usually low, broad, and angular. Much of the illite revealed by X-Ray diffraction may be minute detrital muscovite particles.

Leucoxene, recognized by a white or silver, cottony-wool texture in reflected light and opacity in transmitted light, was observed within quartz grains in minute trace amounts. Leucoxene is a common replacement of titanium bearing minerals such as rutile (Shelley, 1985).

CHAPTER IX

DIAGENSIS AND POROSITY

Chemical processes affecting the Tonkawa Sandstone involved numerous stages of precipitation, dissolution, and replacement. Syntaxial quartz overgrowths, calcite, dolomite, siderite, feldspar overgrowths, chlorite, kaolinite, illite, and pyrite are interpreted as products of precipitation. Primary constituents affected by dissolution include feldspars, calcite, dolomite, fossil fragments, and detrital matrix; however metamorphic rock fragments, muscovite, silica, and siderite all display signs of dissolution. Replacements were also noted, primarily between the carbonates and silica, feldspars, metamorphic rock fragments, detrital matrix, and intraformational clasts. Additionally, dolomite is thought to have locally replaced calcite, and pyrite is observed replacing most of the constituents in several instances.

Paragenesis

Cross-cutting relationships of authigenic and detrital minerals as observed in thin-section were used to develop a generalized sequence of events which have affected the Tonkawa Sandstone post-depositionally (Fig. 34).

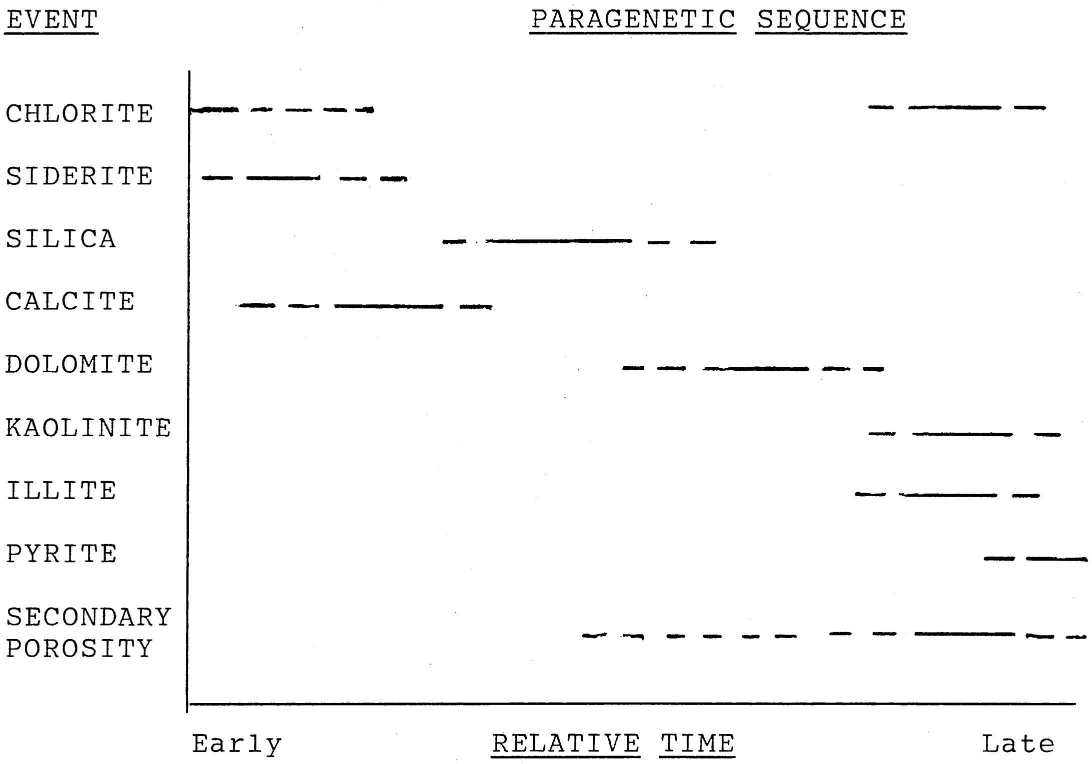

Figure 34. Generalized Paragenetic Sequence

Precipitation of feldspar overgrowths was not included due to their sparsity.

Although alternative interpretations are possible concerning the relationships observed among the various constituents, the following interpretation is thought to be the simplest and involves the fewest number of inferred changes in geochemical conditions which could have led to the relationships observed. A detailed discussion of the specific geochemical parameters and possible sources of ions which may have led to the various events is beyond the scope of this study.

Chlorite is thought to be an early precipitate. Commonly, chlorite rims preserve original detrital grain shape.

Siderite is an early precipitate and replacement mineral. Siderite preserves original grain shape and hinders later diagenesis locally. Siderite was also commonly observed in the vicinity of and replacing intraformational clasts and detrital matrix. Precipitation of siderite may require a source of iron (Berner, 1981). This source could have been provided by chloritic and illitic material which may have originally composed the clasts and matrix.

An early precipitation of calcite is inferred. Syntaxial overgrowths of calcite on echinoderm fragments were observed in several instances (Fig. 35). Precipitation of syntaxial overgrowths on shell fragments

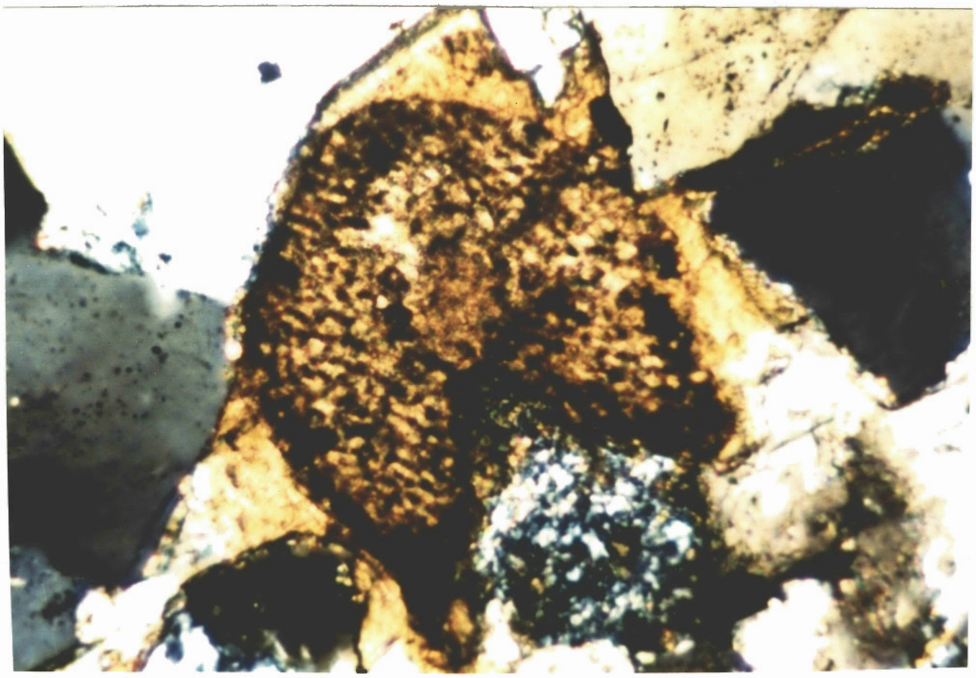

Figure 35. Calcite Overgrowth on Echinoderm Fragment (Farris Unit # 2-7, 7977.5', X200).

may have occured early in shallow marine and phreatic environments (Flugel, 1982). Additional precipitation of calcite at this stage may have led to the poikilotopic calcite crystals which locally hindered later diagenesis in samples containing abundant calcite.

Silica precipitated as syntaxial overgrowths on quartz. Initiation of silica cementation may require temperatures of approximately 80 degress centigrade (Leder and Park, 1986). This temperature suggests a deep burial environment. Precipitation of silica is generally associated with acidic to slightly basic conditions (Leder and Park, 1986). Fossil fragments, early calcite cement, and detrital clay minerals may have been subjected to dissolution in this environment.

Dolomite was observed replacing quartz overgrowths in thin-sections (Fig. 36). This suggests a deep burial phase of dolomitization. Much of the dolomite may be a replacement of early calcite. Megascopic evidence discussed previously in the Farris Unit # 2 - 7 core suggests that dolomite is a replacement of calcite since it occurs above and below a band of calcite cement and the contacts of these cements are very sharp.

Thermal dissociation of kerogen provides organic acids and carbon dioxide which are important in dissolution of metastable constituents such as feldspars, carbonates, rock fragments, and detrital matrix in sandstone reservoirs (Al-Shaieb and Shelton, 1981). Ions released from the

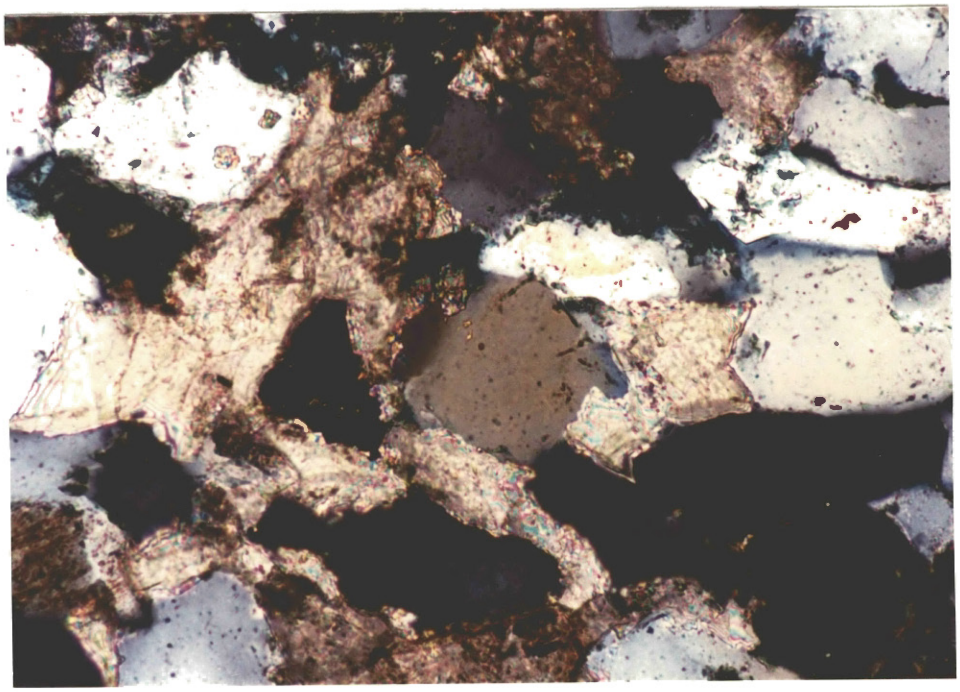

Figure 36. Dolomite Cement Replacing Quartz Overgrowths (Farris Unit # 2-7, 7989', X100).

dissolution of these constituents may be precipitated as authigenic minerals such as clays. Chlorite, illite, and kaolinite in the Tonkawa Sandstone have formed in pore spaces created by the dissolution of various constituents. Chlorite and illite are commonly observed in secondary porosity created by the dissolution of feldspars (Fig. 37). Kaolinite also occurs in pore spaces created by the dissolution of metastable constituents. Kaolinite is thought to be slightly later than chlorite and illite as it is commonly observed filling pore spaces which are rimmed by chlorite and illite.

Pyrite is judged as a very late diagenetic precipitation and replacement event. Pyrite was observed replacing most constituents and precipitated in association with kaolinite in secondary pore space.

Porosity

Primary porosity in the Tonkawa Sandstone was reduced by mechanical compaction and precipitation of cements. Secondary porosity was produced by dissolution of framework grains and cements. Secondary porosity was reduced by the precipitation of clays. Porosity values ranged from 0 to 14 percent in thin-sections. Secondary porosity is the most abundant with minor amounts of preserved primary.

Secondary porosity is distinguished by elongate pores, oversize pores, grain molds, and partial dissolution (Fig. 38) (Schmidt and McDonald, 1979). Dissolution of feldspars

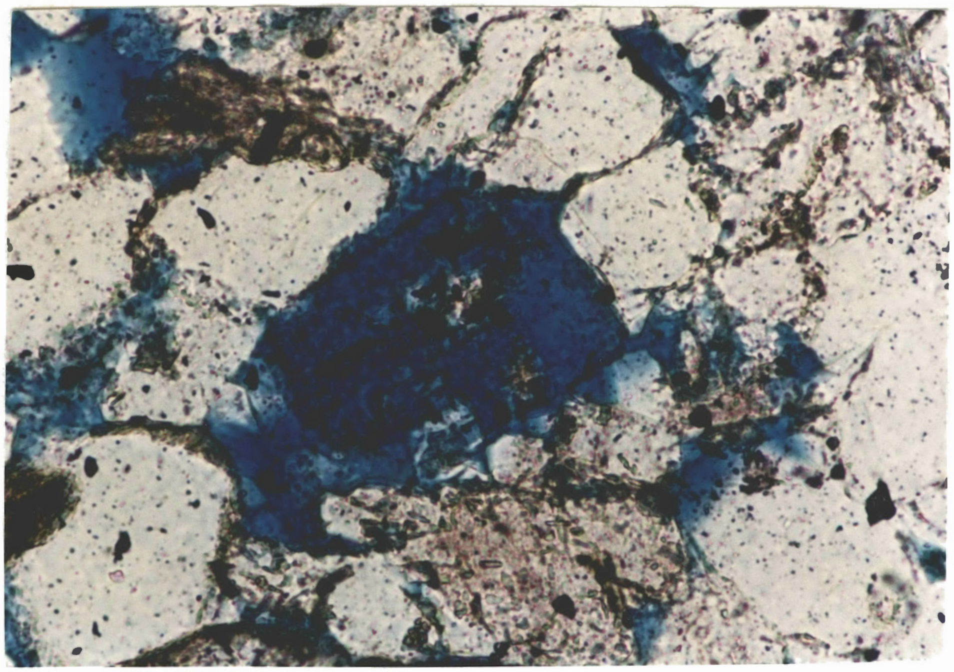

Figure 37. Clays in Pore Space of Dissolved Feldspar (Ellington # 1-35, 7850.5', X100).

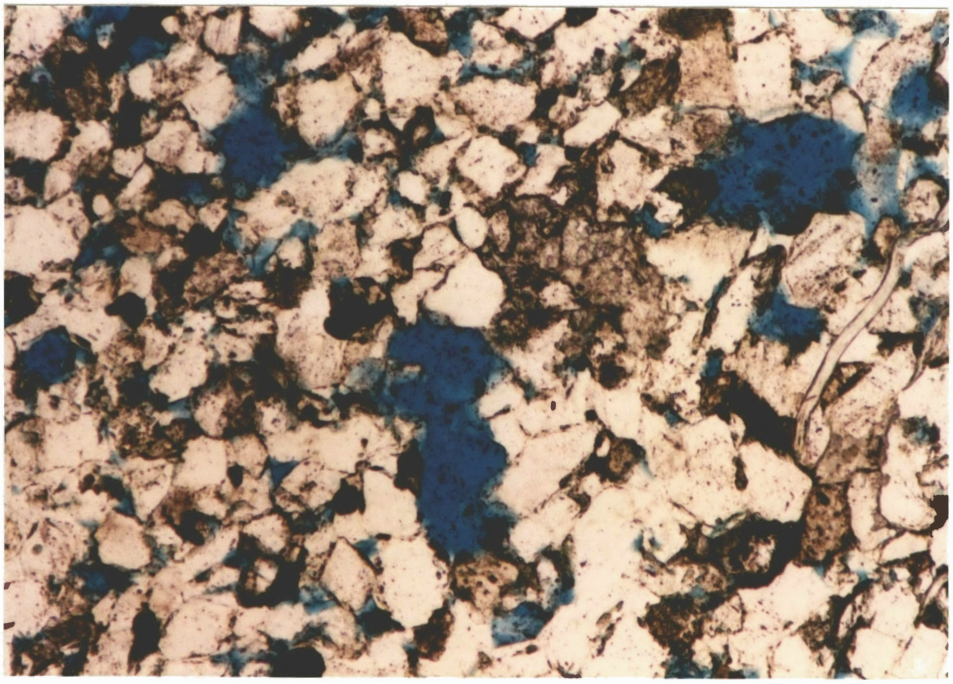

Figure 38. Secondary Porosity Distinguished by Elongate Pores, Oversize Pores, Grain Molds, and Partial Dissolution (Ellington # 1-35, 7853.5', X40).

resulting in honeycombed grains is common in the Tonkawa (Fig. 39). Dissolution of feldspars, shell fragments, and carbonate cements is thought to have produced a majority of the secondary porosity. Shell fragments, silica, carbonate cement, and muscovite, all show signs of dissolution (Fig. 40). Dissolution of detrital matrix occurs locally (Fig. 41).

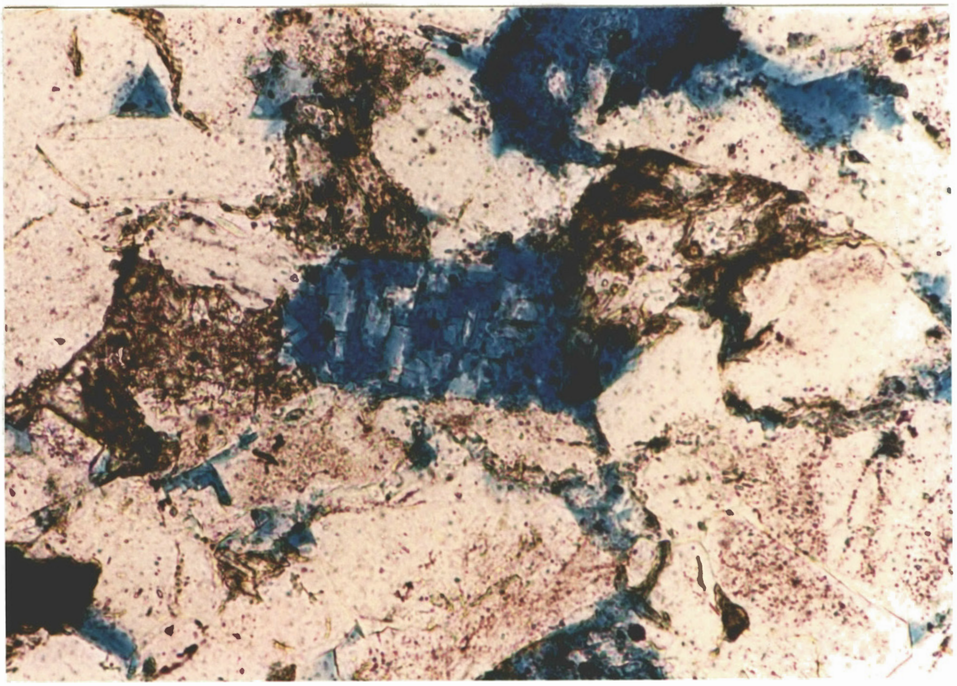

Figure 39. Honeycombed Feldspar Grain (Farris Unit # 2-7, 7951.2', X100).

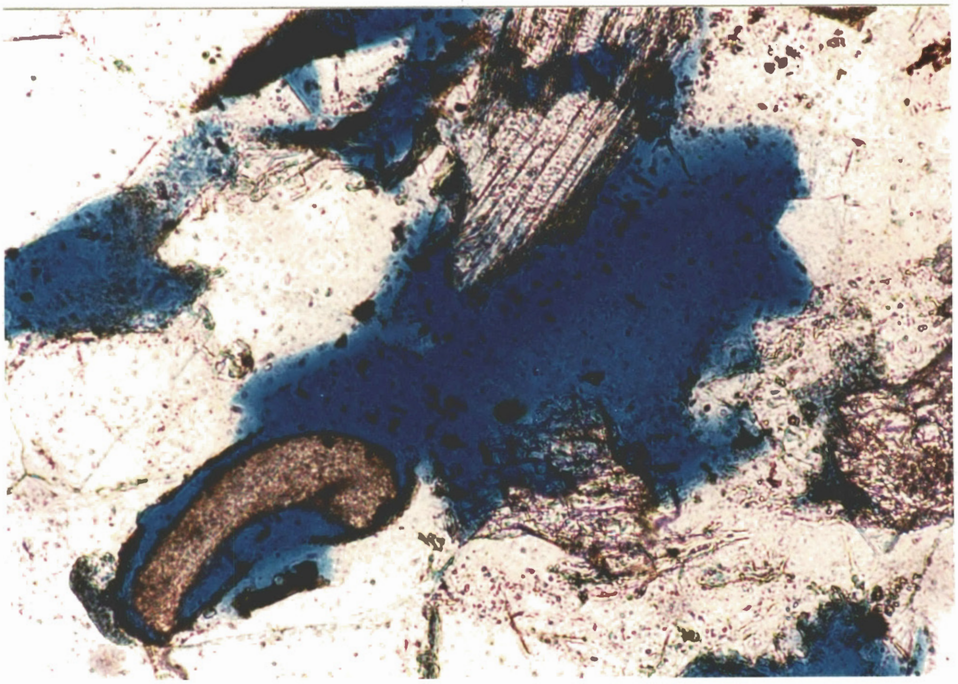

Figure 40. Oversize Pore and Partial Dissolution of Shell Fragment, Carbonate Cement, Silica, and Muscovite (Farris Unit # 2-7, 7975', X200).

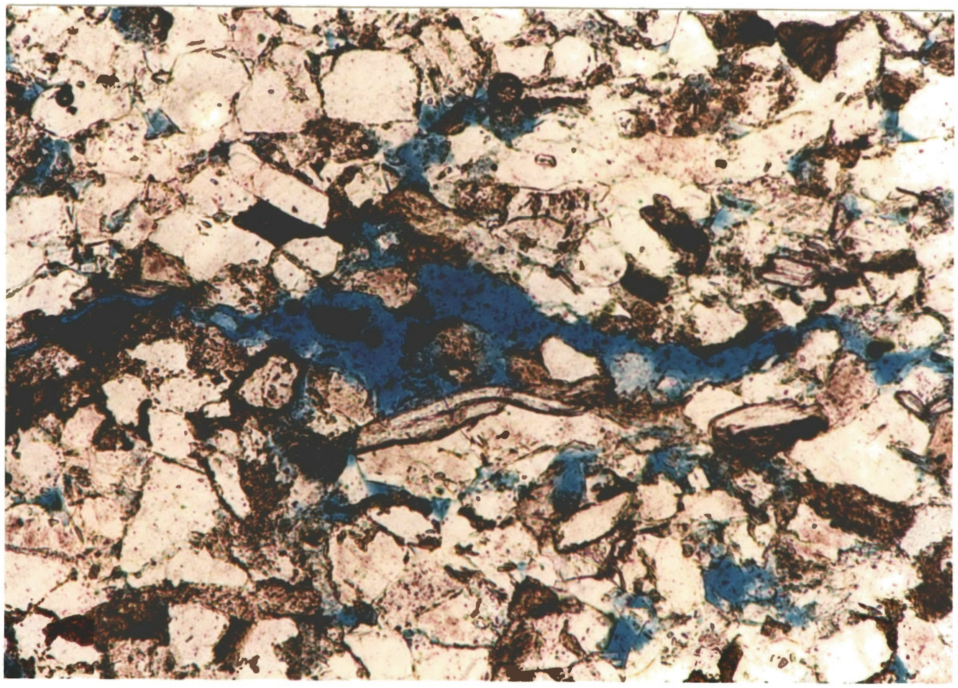

Figure 41. Dissolution of Detrital Matrix Material (Farris Unit # 2-2, 7963', X40).

CHAPTER X

PETROLEUM GEOLOGY

Jordan (1959) lists two early discoveries from the Tonkawa Sandstone in Dewey County, Oklahoma. The Sinclair Kunc # 1 (SW NE, Sec. 11, T17N, R18W) had shows of oil and gas from the Tonkawa in 1957. First production from the Tonkawa was the Sinclair Collier # 1 (NE NE, Sec. 15, T17N, R18W) completed in 1959 initially producing 11 barrels of condensate and 656,000 cubic feet of gas daily. These wells were the original discovery wells in Dewey County (Jordan, 1959). The primary producing zone was the Oswego Limestone.

Slate (1962) identified two additional early wells producing from the Tonkawa. One in section 10, township 17 north, range 18 west, and the Humble Spangler # 1 in section 13, township 17 north, range 19 west. As early production from the Tonkawa occured near a closure, Slate (1962) believed the trapping mechanism would prove to be structural in this area.

Rapid development in the study area occured during the 1960's and 1970's. The locations of Tonkawa production are illustrated (Fig. 42). The main Tonkawa production in the study area is termed, collectively with other zones, the

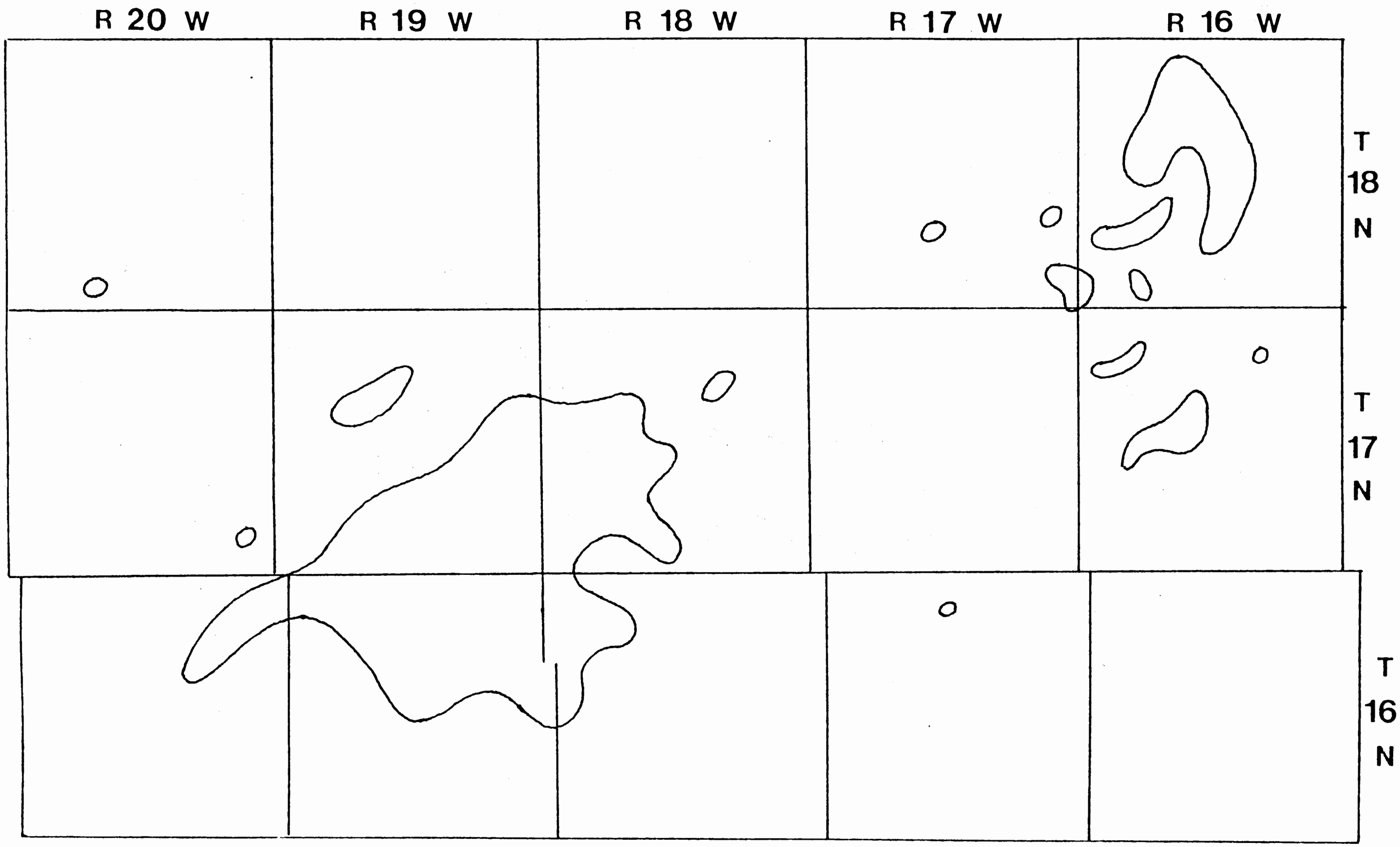

Figure 42. Location of Tonkawa Hydrocarbon Production.

Putnam Field or Putnam Trend (Woncik, 1964; Swanson, 1967).

Cumulative production from the Tonkawa commonly exceeds one billion cubic feet of gas per well in the study area, and rarely exceeds 2 billion cubic feet of gas per well (source, Petroleum Information Corp., 1987). The trapping mechanism is dominantly stratigraphic, occuring where sandstones thin updip into shales. A small combination structural-stratigraphic trap exists in sections 10, 11, 14, and 15, of township 17 north, range 18 west, where a linear sand trend produces on the flank of a closure.

Oil production occurs from a pool in sections 16 through 21, of township 17 north, range 16 west. Other areas produce mainly gas with associated condensate.

Hydrocarbon production from the Tonkawa Interval in the study area occurs from the major sandstone development of the Tonkawa between 70 and 150 feet below the Haskell Marker. Generally, areas displaying disrupted or variable net-sandstone trends along the approximate edge of Tonkawa distribution coincide with areas of the most prolific production (e.g., townships 16 and 17 north, ranges 18 and 19 west; and townships 17 and 18 north, range 16 west).

CHAPTER XI

CONCLUSIONS

The principal conclusions of this study are:

1. The Haskell Limestone is overlain by a persistent marker bed recognizable on gamma ray logs. The Haskell is a fossiliferous, calcareous shale, which may be locally oolitic.

2. The Tonkawa Sandstone is within an interval defined by the Haskell Marker and the Avant Limestone. This interval thickens to the south-southeast at less than 10 feet per mile.

3. The Haskell Marker dips homoclinally to the south-southwest at approximately 50 feet per mile. Anticlinal noses, synclinal troughs, and closures are present.

4. The Tonkawa Sandstones are present as elongate and coalescing lobes. They occur within 150 feet below the Haskell Marker. The thickest sandstones occur between 70 and 150 feet below the base of the Haskell Marker. Net-sandstone thickness is usually less than 45 feet. Dominant net-sandstone trends are in a northeast to southwest direction.

5. Common sedimentary structures include interstratified sandstone and shale, horizontal

laminations, small and medium-scale cross-bedding, soft-sediment deformation features, massive bedding, initial-dip bedding, burrows, and intraformational clasts. Both distinctly fining upward and distinctly coarsening upward sandstone bodies exist.

6. The Tonkawa Sandstones are very fine and fine grained. Sorting ranges from moderate to well. Fossil fragments and glauconite occur, generally in trace amounts. Carbonaceous material is abundant. Wood fragments occur locally.

7. The Tonkawa was deposited in deltaic environments during regressive conditions. Sandstones interpreted as distributary mouth bars are prevalent within the study area. Sandstones thought to be distributary channel fill deposits also occur.

8. The Tonkawa Sandstones are sublitharenites. The primary constituents are monocrystalline and polycrystalline quartz, metamorphic rock fragments, plagioclase feldspars, and muscovite. Zircon is the most abundant heavy mineral.

9. Four authigenic cements are present. These are dolomite, quartz overgrowths, calcite, and siderite. These cements are present in highly variable amounts.

10. Chlorite is the most abundant authigenic clay mineral. Kaolinite is locally abundant. Illite is present in trace amounts as an authigenic mineral.

11. Porosity is mostly secondary and is chiefly due

to dissolution of feldspars, shell fragments, and carbonate cements. Additional secondary porosity is due to dissolution of detrital matrix, silica, and muscovite.

12. Prolific hydrocarbon production occurs along the approximate southeastern limit of Tonkawa Sandstone distribution in the study area. All hydrocarbon production occurs from the major sandstone development of the Tonkawa which is betwen approximately 70 and 150 feet below the Haskell Marker. Trapping mechanism is predominantly stratigraphic.

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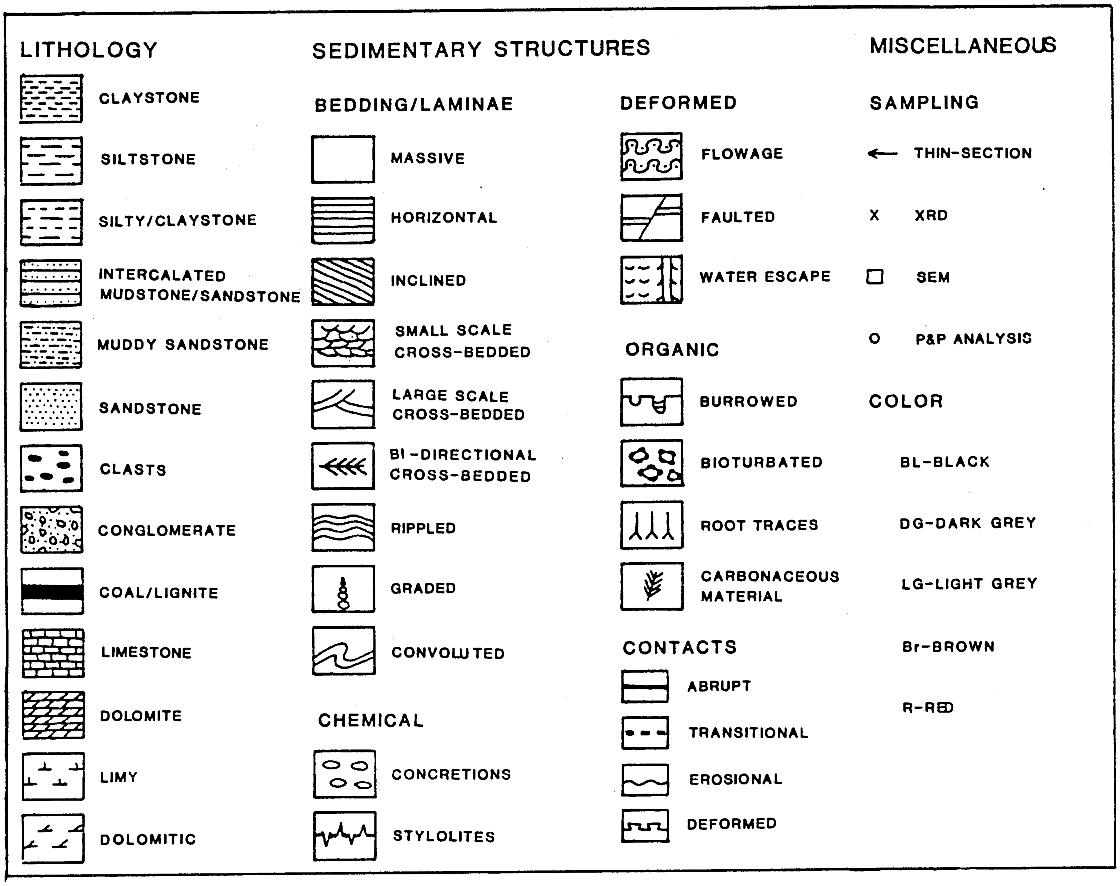
APPENDIX

CORE PETROLOGIC LOGS
AND SUMMARIES


LITHOLOGY
CLAYSTONE
SILTSTONE
SILTY/CLAYSTONE
INTERCALATED MUDSTONE/SANDSTONE
MUDDY SANDSTONE
SANDSTONE
CLASTS
CONGLOMERATE
COAL/LIGNITE
LIMESTONE
DOLOMITE
LIMY
DOLOMITIC
SEDIMENTARY STRUCTURES
BEDDING/LAMINAE
MASSIVE
HORIZONTAL
INCLINED
SMALL SCALE CROSS-BEDDED
LARGE SCALE CROSS-BEDDED
BI-DIRECTIONAL CROSS-BEDDED
RIPPLED
GRADED
CONVOLUTED
CHEMICAL
CONCRETIONS
STYLOLITES
DEFORMED
FLOWAGE
FAULTED
WATER ESCAPE
ORGANIC
BURROWED
BIOTURBATED
ROOT TRACES
CARBONACEOUS MATERIAL
CONTACTS
ABRUPT
TRANSITIONAL
EROSIONAL
DEFORMED
MISCELLANEOUS
SAMPLING
← THIN-SECTION
X XRD
□ SEM
O P&P ANALYSIS
COLOR
BL-BLACK
DG-DARK GREY
LG-LIGHT GREY
Br-BROWN
R-RED

WELL: McCulloch Oil Corp., Craig # 1 - 6

LOCATION: NW NW NW SE 6 - 17N - 20W

CORED DEPTH: 8025' - 8095'

WELL STATUS: Dry and Abandoned
Perfs.: 8025' - 8075'

CORE SUMMARY:

The unit from the base of the core to 8068' consists of interstratified sandstones and shales with a dominance of ripples and small-scale cross-bedding, but also displaying burrows and soft-sediment deformation structures. The sandstones are fine and very fine grained, moderately sorted, dolomite cemented, nonporous, and contain traces of glauconite and shell fragments. This unit is interpreted as a distal bar deposit.

The next unit (8068' to 8037') is a sequence of sandstones with interbedded shales. The sandstones display medium-scale cross-bedding, massive beddding, and small-scale cross-bedding. Sideritized, pebbly, intraformational clasts occur locally. The sands are fine and very fine grained, moderately to moderately well sorted, porous, and cemented by quartz, dolomite, and siderite. The interbedded shales contain lenticular laminations and soft-sediment deformations. Abrupt contacts at the base of sandstones which may be erosional are evident in this unit. Possible subareial exposure occurs at 8047.5' where a medium-scale cross-bedded sandstone with up to 19% siderite is abruptly overlain by a coarsening upward, interstratified sandstone and shale sequence. The sandstones in this unit are interpreted as distibutary channels.

The interstratified sandstones and shales from 8037' to 8031' display ripples, lenticular laminations, and burrows. The amount of burrowing increases upward. This unit is interpreted to be an interdistibutary bay fill deposit.

At the top of the core is a sandstone with medium-scale cross-bedding at the base and horizontal laminations and small-scale cross-bedding above. Shale content increases upward. The sands are fine grained, moderately sorted, porous, and cemented by siderite and quartz. This unit is interpreted as a small point bar.

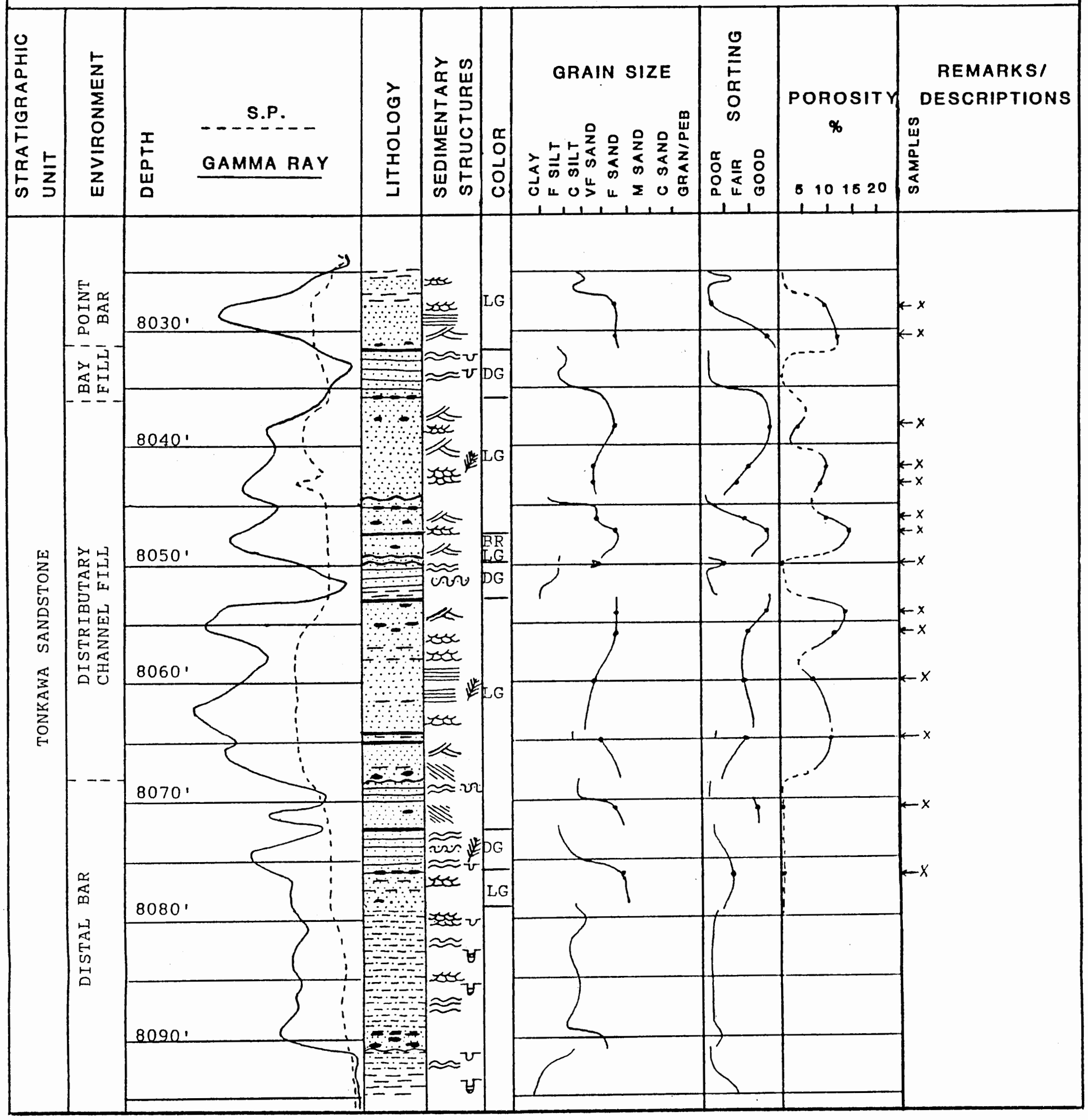
PETROLOGIC LOG

WELL: McCULLOCH OIL CORP., CRAIG # 1 - 6

LOCATION: NW NW NW SE
6 - 17N - 20W

CORED INTERVAL: 8025' - 8095'

DEPTH CORRECTION: CORE DEPTH≃LOG DEPTH-7'



WELL: Texas Oil and Gas Corp., Saylor A # 1

LOCATION: SE 24 - 17N - 19W

CORED DEPTH: 7895' - 7953'

WELL STATUS: Oil and Gas
Perfs.: 7906' - 7953'
I.P.: 1,920 MCFGPD + 22BO + 22BW/24hrs.
Cum.: 2/74 - 5/85; 9,367 BO
2/74 - 6/86; 882,742 MCFG

CORE SUMMARY:

From the base of the core to 7939' is a sequence of interstratified sandstones and shales. Sedimentary structures include ripples, small-scale cross-bedding, horizontal laminations, and soft-sediment deformation features. Individual sandstones generally fine upward. Burrows are present but not common. The sandstones are very fine grained, moderately sorted, dolomite and quartz cemented, and contain up to 1% each of shell fragments and glauconite. The sandstone from 7954'to 7952' is fine grained, contains pebbly, sideritized intraformational clasts, is porous and productive. This sequence is thought to represent distal bar deposits.

The unit from 7939' to 7920' is composed of a generally coarsening upward sandstone containing a few pebbly, sideritized, intraformational clasts. Sedimentary structures include massive bedding, small-scale cross-bedding, soft-sediment deformation structures, and faint horizontal laminations. The sands are fine and very fine grained, moderately well sorted, dolomite and quartz cemented, and contain traces of glauconite and shell fragments. This unit is interpreted as representing a distributary mouth bar. This unit is productive.

From 7920' to the top of the core is a sequence of interstratified sandstones and shales displaying a dominance of ripples and small-scale cross-bedding. Both fining upward and coarsening upward sandstones occur. Pebbly, sideritized intraformational clasts occur locally. The sands are fine and very fine grained, moderately sorted, quartz cemented, and contain traces of glauconite. The sand from 7910' - 7914' is porous and probably productive. The depositional environment interpretation of this unit is that it represents interdistributary bay fill deposits.

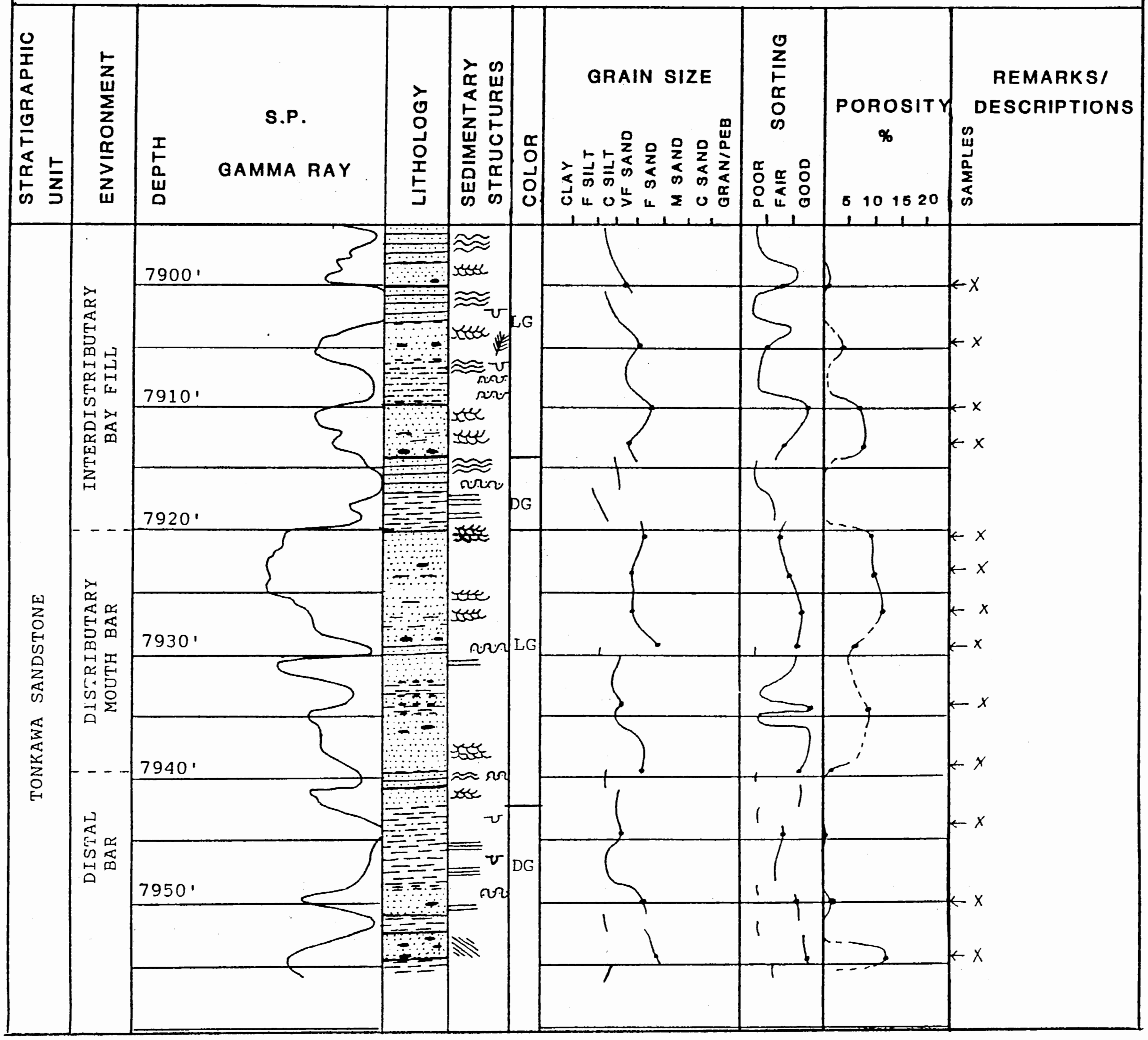
PETROLOGIC LOG

WELL: TEXAS OIL & GAS CORP.,
SAYLOR A # 1

LOCATION: SE 24 - 17N - 19W

CORED INTERVAL: 7895' - 7956'

DEPTH CORRECTION: CORE DEPTH≃LOG DEPTH



WELL: Wessely Energy Corp., Ellington # 1 - 35

LOCATION: S/2 S/2 NE NW 35 - 17N - 19W

CORED DEPTH: 7845' - 7945'

WELL STATUS: Oil and Gas
Perfs.: 7844' - 7885'
I.P.: 1,460 MCFGPD + 28BO + 12BW/24hrs.
Cum.: 8/79 - 5/85; 6,720 BO
9/79 - 6/86; 829,800 MCFG

CORE SUMMARY:

From the base of the core to 7889' is a dark gray shale with horizontal laminations of siltstone. Lenticular laminations and burrows occur but are not common.

The sandstone from 7889' to 7881' displays ripples, small-scale cross-beds and massive bedding. The sandstone coarsens upward and contains pebbly, sideritized, intraformational clasts in the upper portions where medium-scale cross-bedding occurs. The sandstone is fine and very fine grained, moderately well sorted, cemented by dolomite, and is porous. Shell fragments and glauconite occur up to 1%. The lower contact of this unit is transitional, the upper contact is abrupt. This sandstone is interpreted as a distributary mouth bar. This unit is productive.

From 7881' to 7865' is a sequence of interstratified sandstones and shales displaying ripples, small-scale cross-bedding, soft-sediment deformation structures, and burrows. Carbonaceous material occurs locally along bedding planes. Fragments of coal and/or woody material occur locally in sandstone. The sandstones are fine and very fine grained, moderately sorted, nonporous, dolomite and quartz cemented, and contain traces of shell fragments and glauconite.

The sandstones from 7865' to the top of the core display medium-scale cross-bedding, massive bedding, small-scale cross-bedding, and horizontal laminations. Pebbly, sideritized, intraformational clasts occur but are not abundant. Shale content increases upward. Slumped sandstone and shale occur in the upper portions. This unit displays highly variable grain size trends. The sands are very fine and fine grained, moderately well sorted, quartz and dolomite cemented, and are porous. This unit is interpreted as distributary channel fill deposits. This sand is productive.

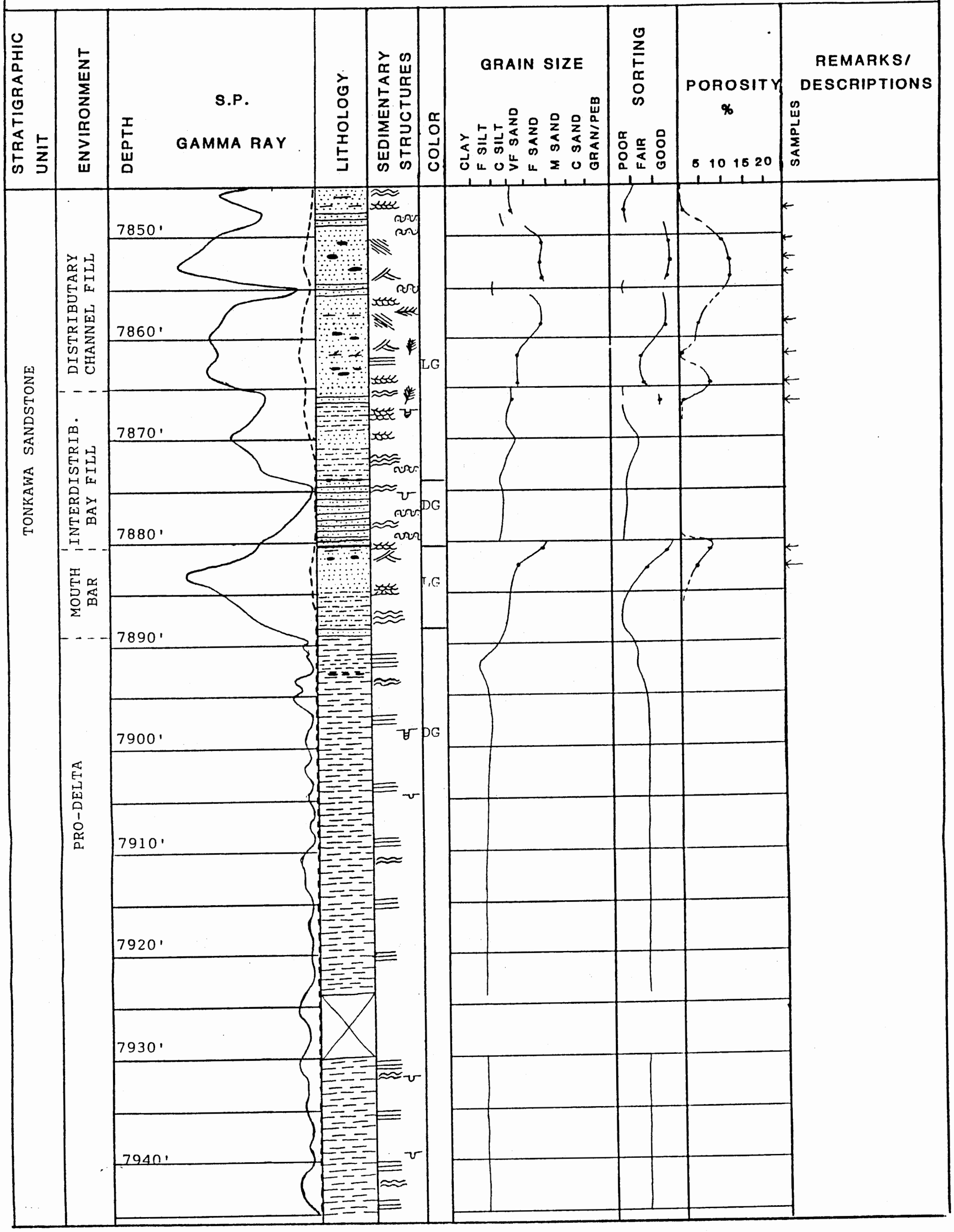
PETROLOGIC LOG

WELL: WESSELY ENERGY CORP.,
ELLINGTON # 1 - 35

CORED INTERVAL: 7845' - 7945'

LOCATION: S/2 S/2 NE NW
35 - 17N - 19W

DEPTH CORRECTION: CORE DEPTH≃LOG DEPTH+2'



WELL: Wessely Energy Corp., Farris Unit # 2 - 2

LOCATION: E/2 NW 2 - 16N - 19W

CORED DEPTH: 7857' - 8017'

WELL STATUS: Oil and Gas
Perfs.: 7952' - 7990'
I.P.: 1,263 MCFGPD + 15BO + 3.5BW/24hrs.
Cum.: 9/79 - 6/86; 523,900 MCFG

CORE SUMMARY:

The unit at the base of the core to 7993' is a dark gray shale displaying horizontal and lenticular laminations of siltstone. Burrows and ripples are present.

The next unit (7993' to 7981') is a light gray sandstone with minor amounts of pebbly, sideritized, intraformational clasts. Sedimentary structures include massive bedding and small-scale cross-bedding. An interbedded shale contains soft-sediment deformation features. The sandstones coarsen upward from the base and also fine upward to the top. The bounding contacts of the unit are transitional. This unit is intepreted as representing a distributary mouth bar.

The unit from 7981' to 7972' is composed of interstratified sandstone and shale. Sedimentary structures include a dominance of ripples and small-scale cross-bedding. Burrows are also present. Carbonaceous material occurs locally along bedding planes.

The sandstone from 7972' to 7947' is a light gray, coarsening upward unit displaying massive bedding and small- scale cross-bedding in the lower portions and horizontal laminations, massive bedding, and medium-scale cross-bedding in the upper portions. Pebbly, sideritized, intraformational clasts and sideritized clay drapes occur. Disseminated carbonaceous material occurs in the lower portions. Much of this unit was missing. The sandstones are fine and very fine grained, moderately well sorted, quartz and dolomite cemented, and porous. Glauconite and shell fragments occur in trace amounts in the lower sands. The lower contact of this unit is transitional, the upper contact is abrupt. This sandstone is interpreted as representing a distributary mouth bar. This unit is productive.

The next unit (7947' to 7889') is a sequence of interstratified sandstone and shale with a dominance of ripples, small-scale cross-bedding, horizontal laminations and burrows. Individual sandstone beds have both abrupt and transitional bases. This sequence is possibly interdistributary bay fill transitional upward into prodeltaic deposits.

From 7889' to 7869' is a sequence of interstratified sandstones and shales. The lower sandstone in this unit displays black, pebbly, intraformational clasts, horizontal laminations, and small-scale cross-bedding. The upper sandstones are rippled and burrowed. The bounding contacts of this unit are abrupt. These sands may represent the distal portions of a second delta lobe.

The next unit (7869' to 7859') is a dark gray to black, horizontally laminated shale. Several thin reddish-brown bands of siderite occur in the upper portions of this shale.

The unit at the top of the core is a dark gray, fossiliferous, silty, organic rich, calcareous shale which grades upward into slightly fossiliferous, black shale. Fossils include brachiopods, crinoid columnars, and unidentified microfossils. The base of this unit is abrupt. This unit is thought to represent open marine conditions.

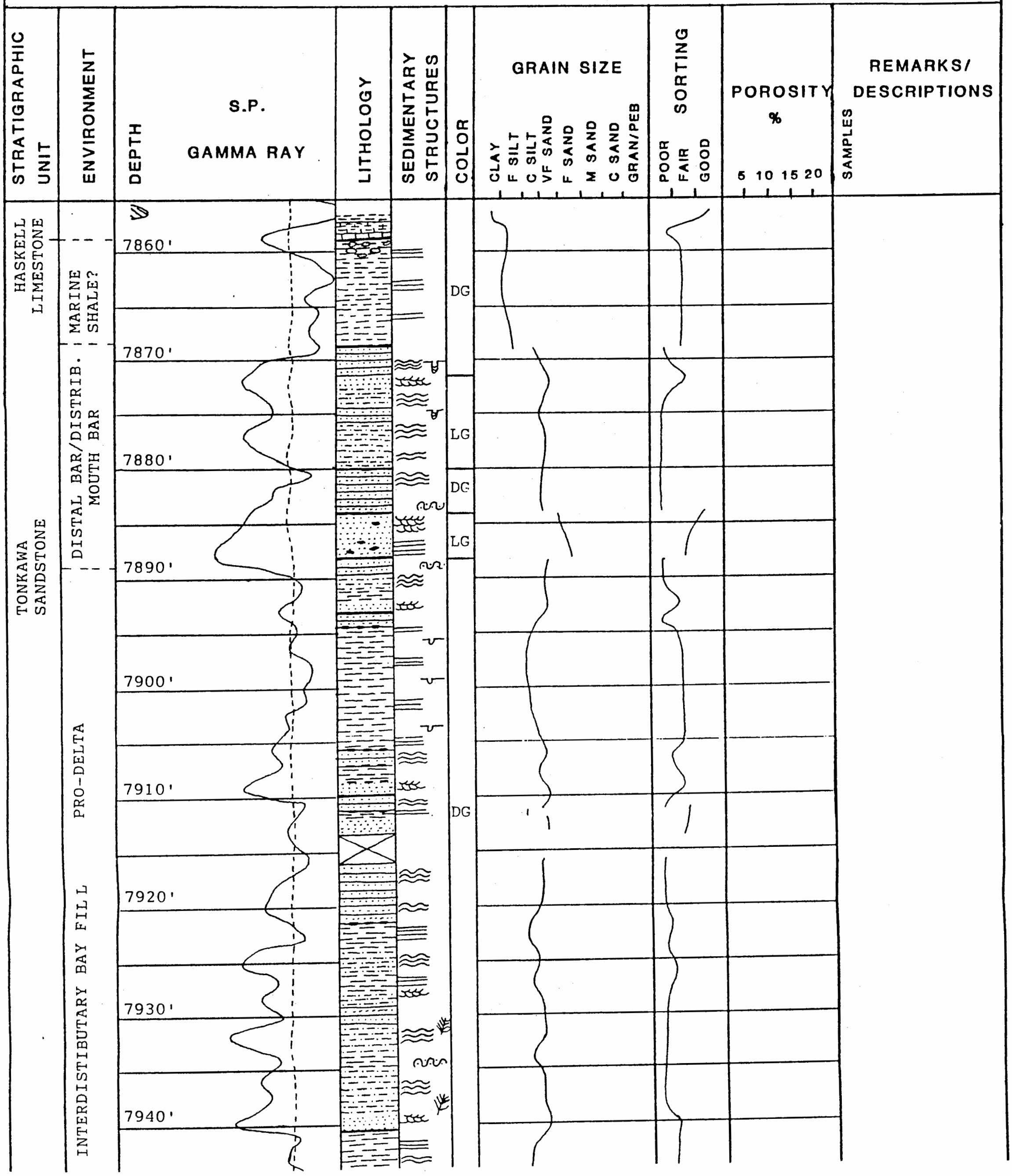
PETROLOGIC LOG

WELL: WESSELY ENERGY CORP.
FARRIS UNIT # 2 - 2

LOCATION: E/2 NE 2 - 16N - 19W

CORED INTERVAL: 7857' - 8017'

DEPTH CORRECTION: CORE DEPTH≃LOG DEPTH



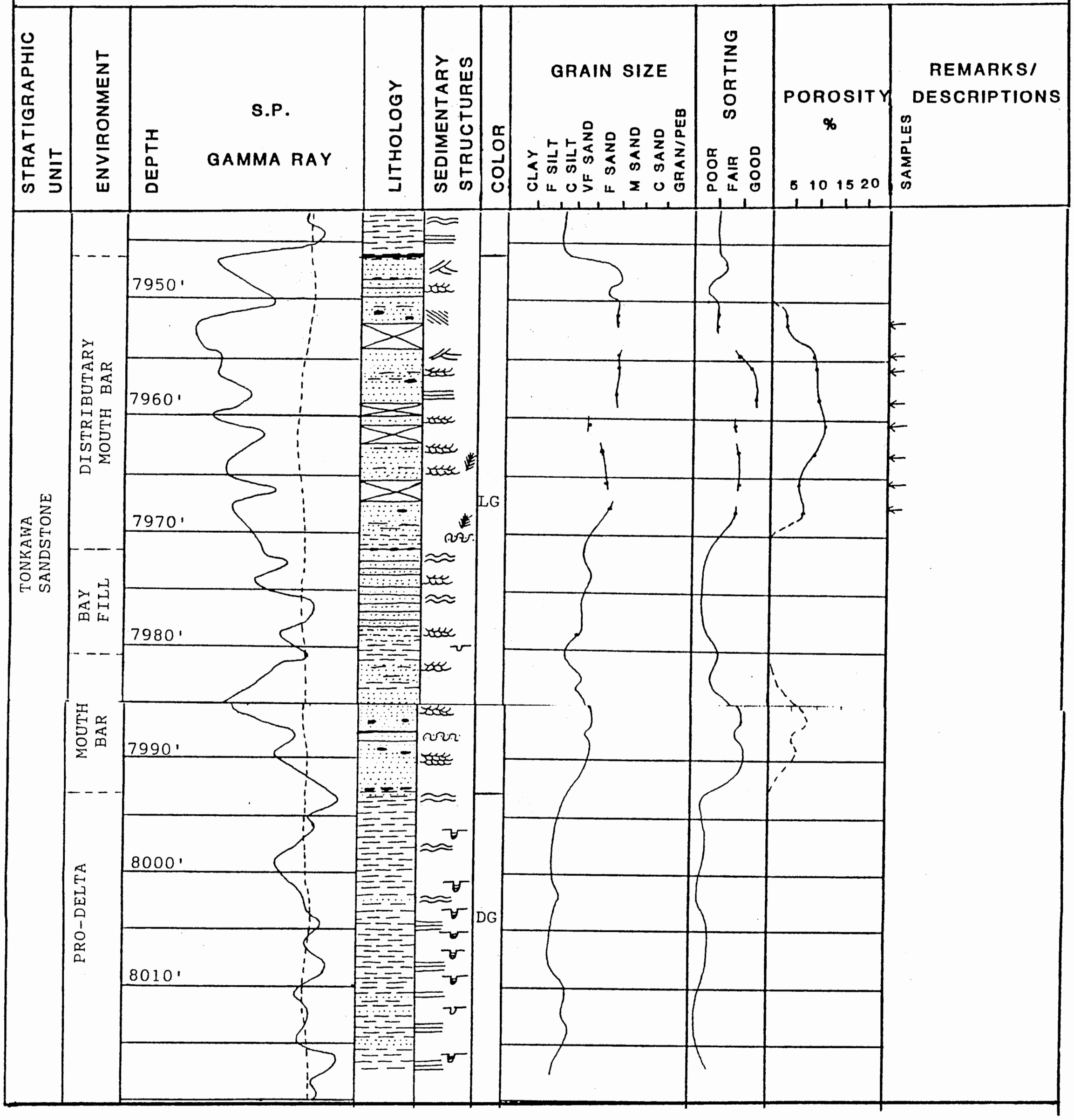
PETROLOGIC LOG

WELL: WESSELY ENERGY CORP.
FARRIS UNIT # 2 - 2

LOCATION: E/2 NE 2 - 16N - 19W

CORED INTERVAL: 7857' - 8017'

DEPTH CORRECTION: CORE DEPTH≃LOG DEPTH



WELL: Wessely Energy Corp., Farris Unit # 2 - 7

LOCATION: NE 7 - 16N - 18W

CORED DEPTH: 7910' - 8022'

WELL STATUS: Oil and Gas
Perfs.: 7942' - 7990'
I.P.: 910 MCFGPD + 28BO + 10BW/24hrs.
Cum.: CMGD with Cottage Grove

CORE SUMMARY:

The unit at the base of the core to 7998' is a dark gray shale with horizontal and lenticular laminations of siltsone and a few silt-filled burrows. Disseminated carbonaceous material occurs but is not abundant. Individual silt laminae become more numerous upward.

The next unit (7998' to 7971') is a coarsening upward, light gray sandstone . Ripples and small-scale cross-bedding are the dominant sedimentary structures. Soft-sediment deformation structures and burrows occur in the lower portions of this unit where interstratified sandstones and shales are more common. Pebbly, sideritized, intraformational clasts and sideritized clay drapes also occur in this unit. The sandstones are moderate to moderately well sorted, very fine and fine grained, and are cemented by quartz, dolomite, and calcite. Glauconite and shell fragments occur in trace amounts in this unit, generally decreasing in abundance upward. The lower contact of this unit is transitional, the upper contact is abrupt. This sandstone is interpreted as representing a distributary mouth bar. This unit is productive.

From 7971' to 7957' is a sequence of interstratified sandstone, siltstone , and shale. Soft-sediment deformation features are dominant. Slumped structures are common. Carbonaceous material occurs associated with ripples. Thin, massive, black, organic rich shales occur. A sandstone at 7971' contains abundant rounded, pebbly, sideritized, intraformational clasts and up to 3% shell fragments as well as traces of reworked oolites. This unit may represent an abandoned distributary channel fill deposit.

The sandstone from 7957' to 7942' is dominated by massive bedding, small-scale cross-bedding, and horizontal laminations. Interlaminated shales are present as well as a thin zone with up to 30% carbonaceous material at 7952'. The sandstone are fine and very fine grained, moderately sorted, quartz cemented, and porous. The bounding contacts of this unit are abrupt. This sand is interpreted as representing a distributary channel sand. This unit is productive.

The unit at the top of the core consists of interstratified sandstones and shales. Horizontal and lenticular laminations, and small-scale cross-bedding are the dominant sedimentary structures. The sandstones have generally transitional lower contacts and abrupt upper contacts. Carbonaceous material occurs locally along bedding planes. The sands are very fine grained, moderately sorted, calcite cemented, and contain traces of glauconite. This unit is interpreted as an interdistributary bay fill deposit.

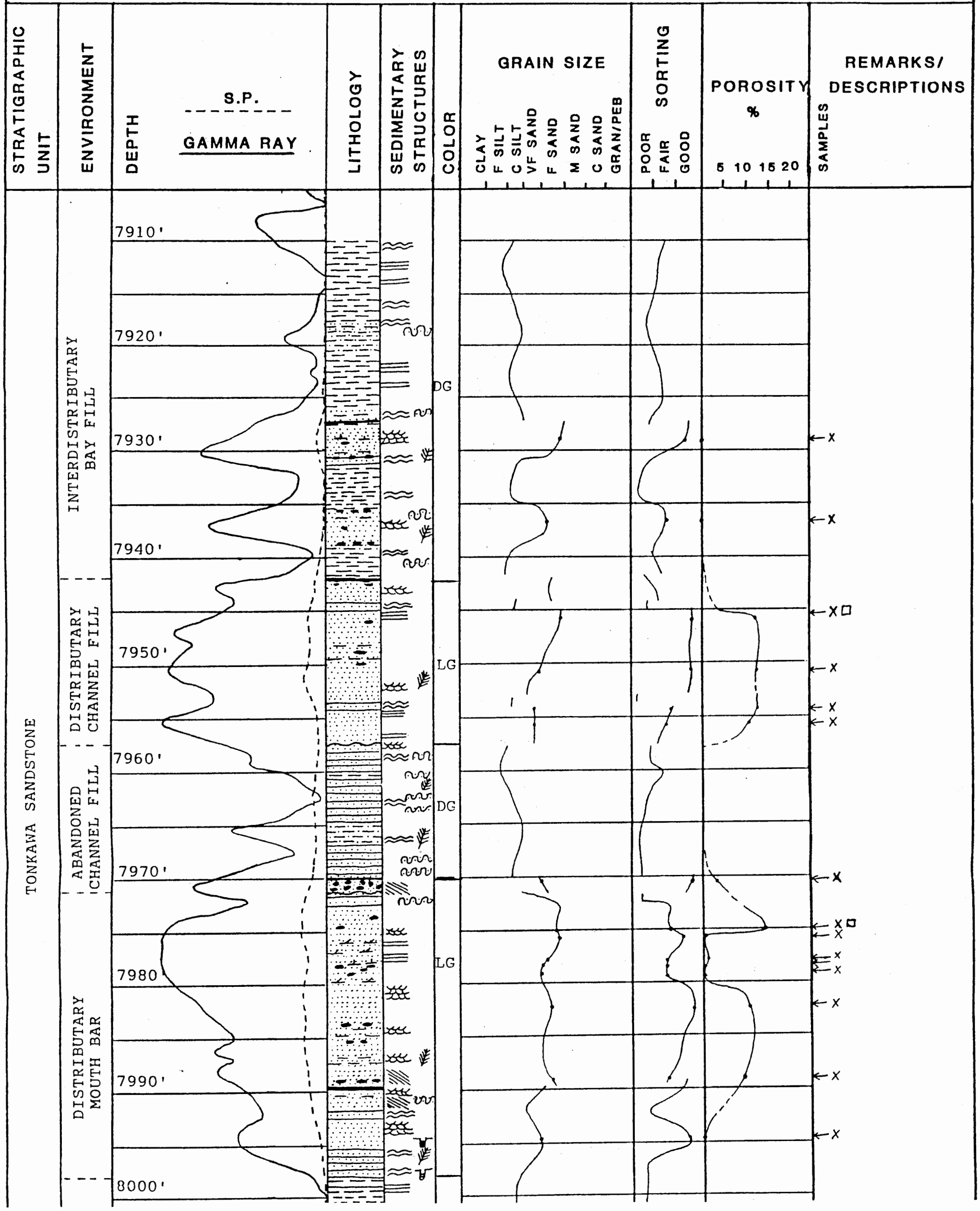
PETROLOGIC LOG

WELL: WESSELY ENERGY CORP.,
FARRIS UNIT # 2 - 7

LOCATION: NE 7 - 16N - 18W

CORED INTERVAL: 7910' - 8022'

DEPTH CORRECTION: CORE DEPTH≃LOG DEPTH

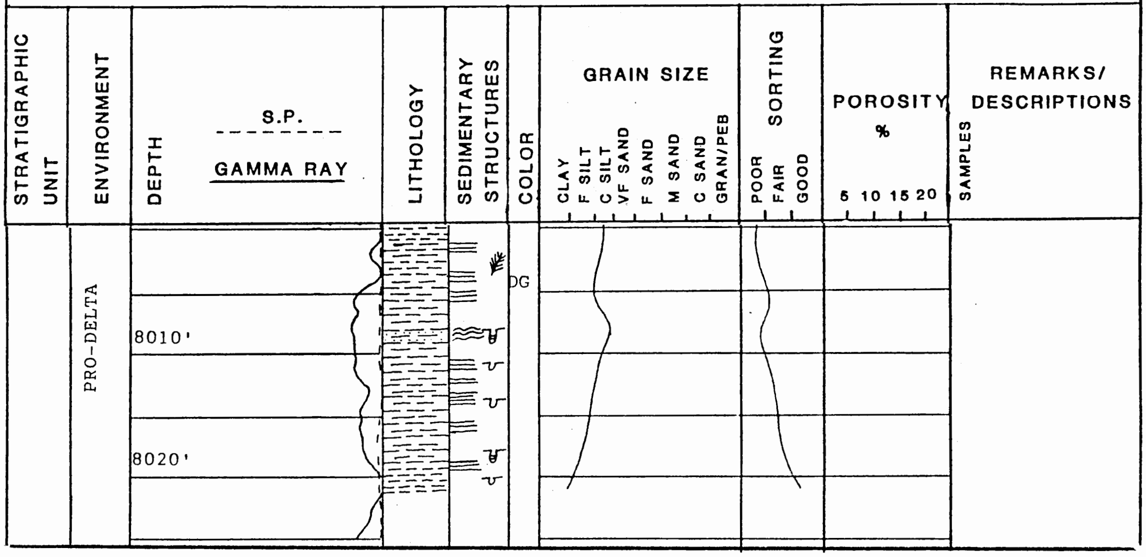


PETROLOGIC LOG

WELL: WESSELY ENERGY CORP.,
FARRIS UNIT # 2 - 7
CORED INTERVAL: 7910' - 8022'

LOCATION: NE 7 - 16N - 18W

DEPTH CORRECTION: CORE DEPTH≃LOG DEPTH



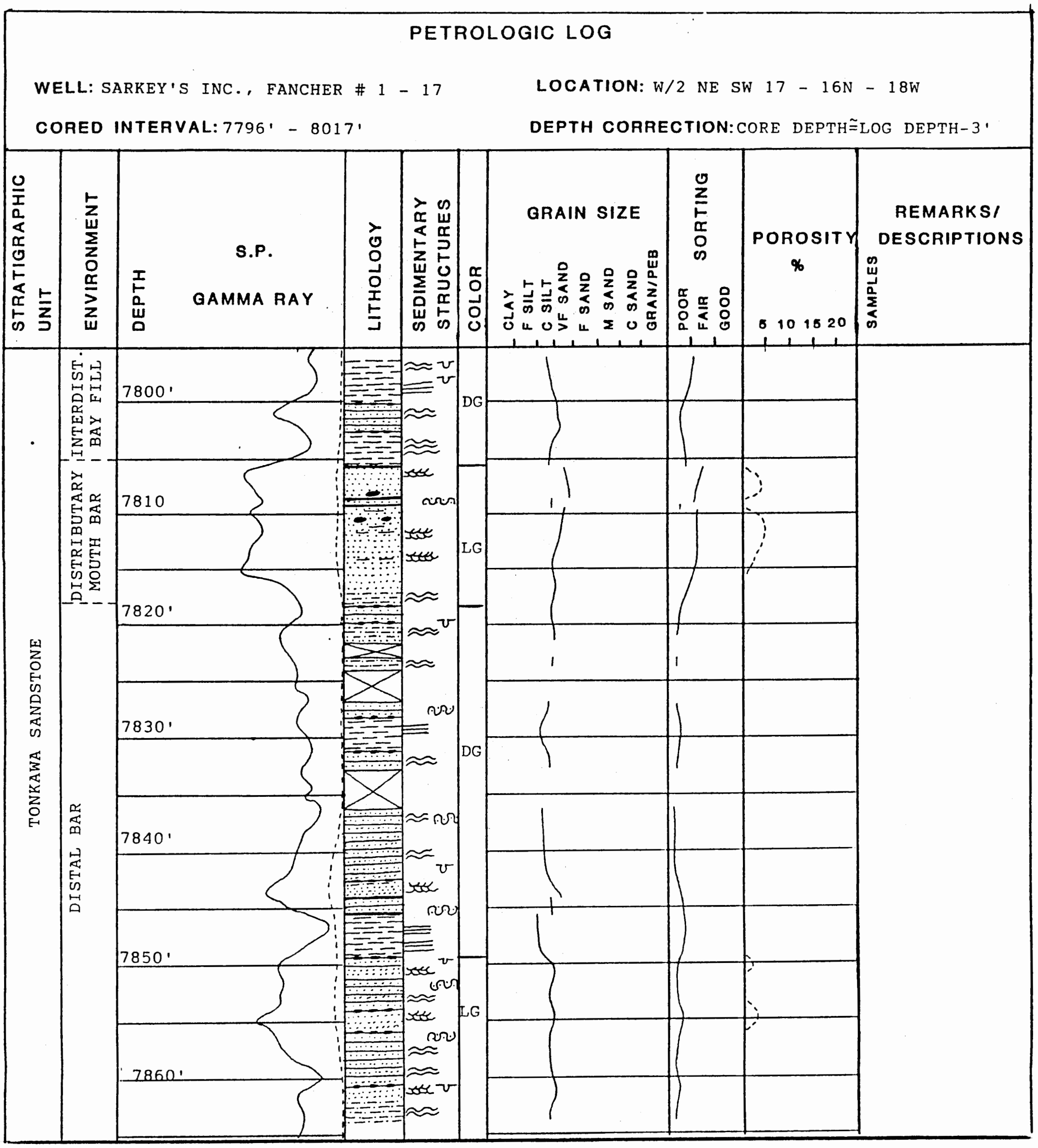
WELL:	Sarkey's Inc., Fancher # 1 - 17
LOCATION:	W/2 NE SW 17 - 16N - 18W
CORED DEPTH:	7796' - 7863'
WELL STATUS:	Dry and Abandoned Perfs.: 7803' - 7853'

CORE SUMMARY:

From the base of the core to 7818' is a sequence of interstratified sandstones and shales displaying a dominance of ripples and small-scale cross-bedding. Burrows and soft-sediment deformation structures also occur. The contacts between sandstone and shale are generally transitional. This unit is interpreted as distal bar deposits.

The unit from 7818' to 7805' is a light gray, generally coarsening upward, massively bedded, and small-scale cross-bedded sandstone. Black, pebbly, intraformational clasts occur in the upper portions of this unit. The lower contact of this unit is transitional, the upper contact is abrupt. This sandstone is interpreted as representing a distributary mouth bar.

From 7805' to the top of the core is a shale with interstratified sandstones displaying ripples, burrows, and minor amounts of horizontal laminations. The sandstones have generally transitional bases and both abrupt and transitional upper contacts. This unit probably represents interdistributary bay fill deposits.



PETROLOGIC LOG

WELL: SARKEY'S INC., FANCHER # 1 - 17

LOCATION: W/2 NE SW 17 - 16N - 18W

CORED INTERVAL: 7796' - 8017'

DEPTH CORRECTION: CORE DEPTH≅LOG DEPTH-3'

2

VITA

Philip C. O. Padgett

Candidate for the Degree of

Master of Science

Thesis: PETROLOGY, DIAGENESIS, AND DEPOSITIONAL ENVIRONMENT OF THE TONKAWA SANDSTONE IN SOUTHWESTERN DEWEY COUNTY, OKLAHOMA

Major Field: Geology

Biographical:

Personal: Born in Wapenamanda, Papua, New Guinea, June 1, 1962, the son of Stanley D. and Norma F. Padgett.

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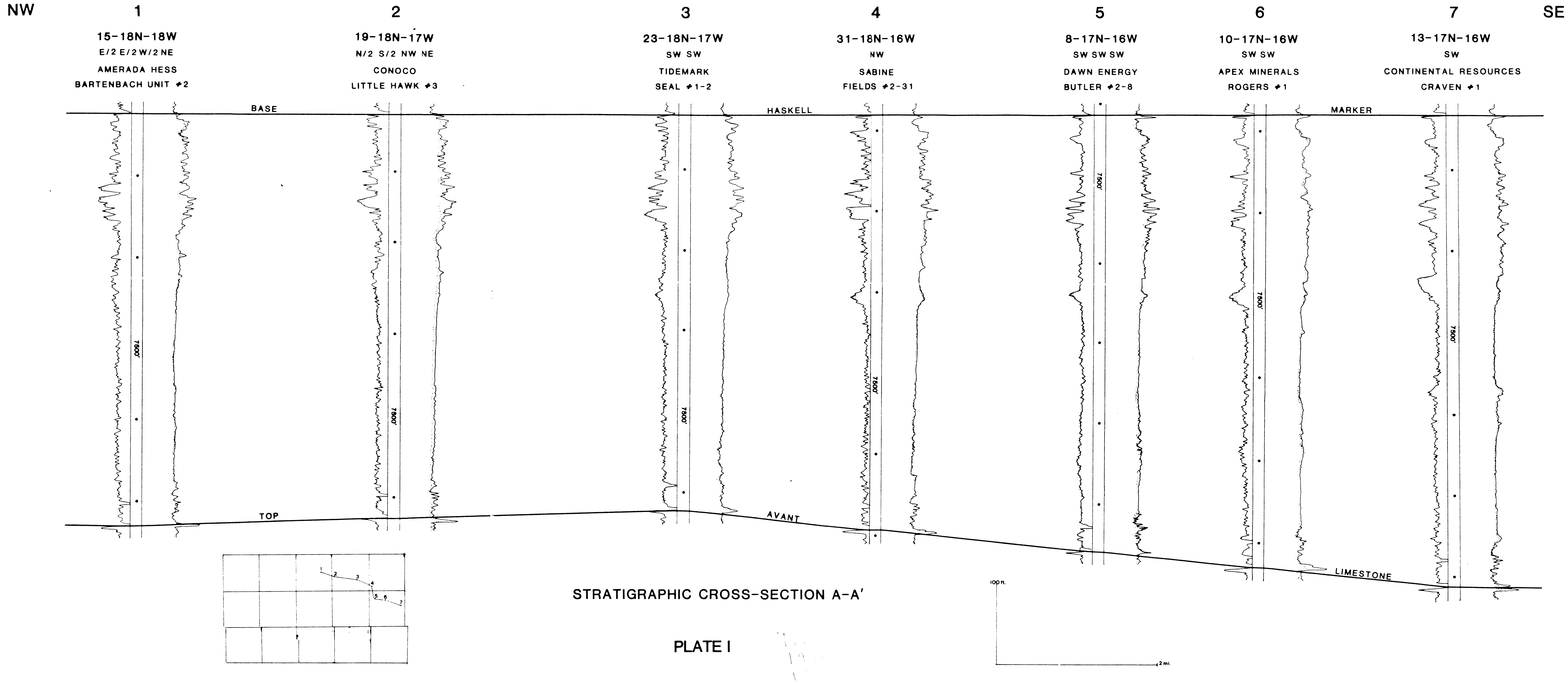
Professional Experience: Junior member of the American Association of Petroleum Geologists; Teaching Assistant, Oklahoma State University, 1986 to 1988

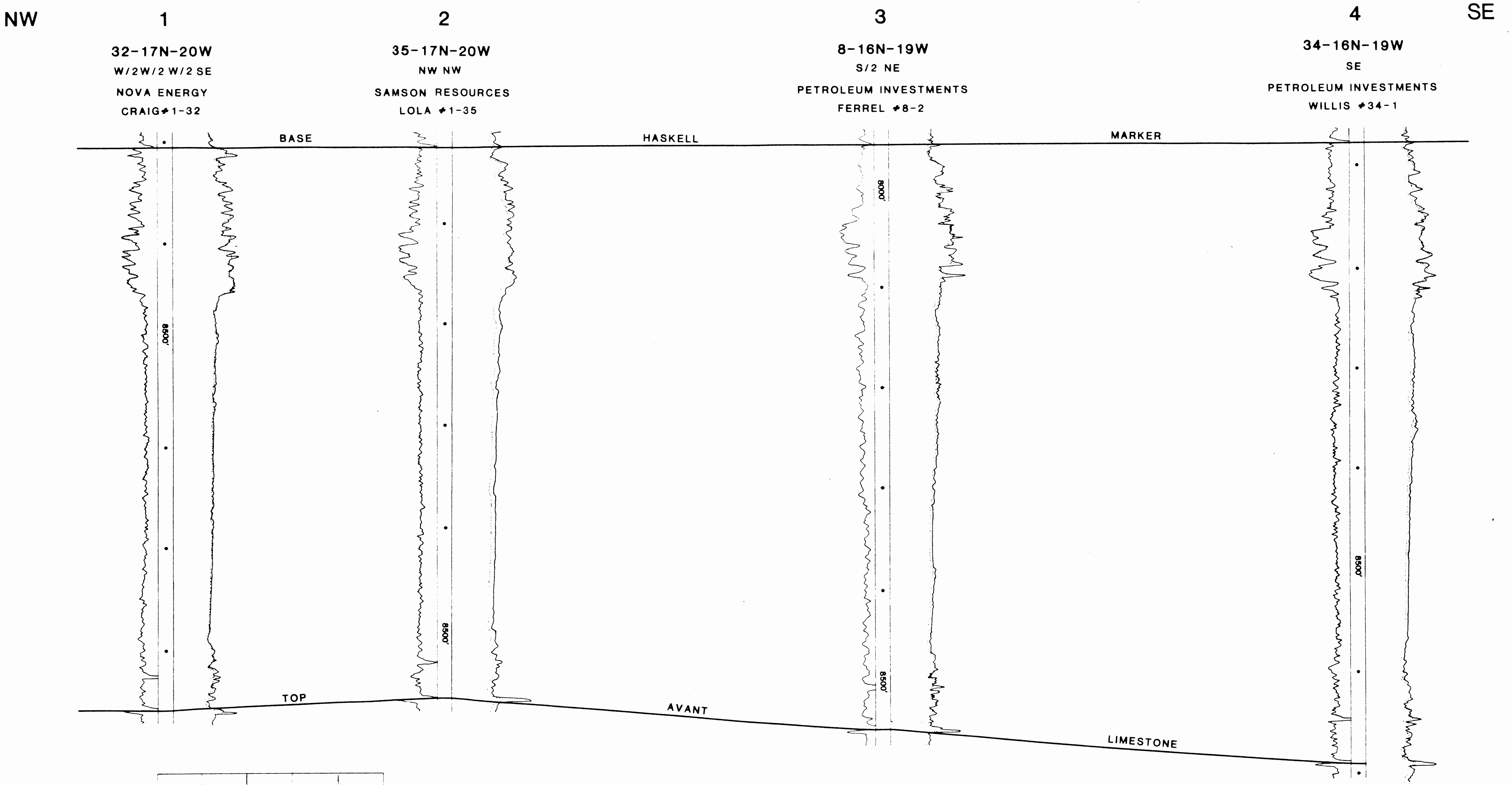


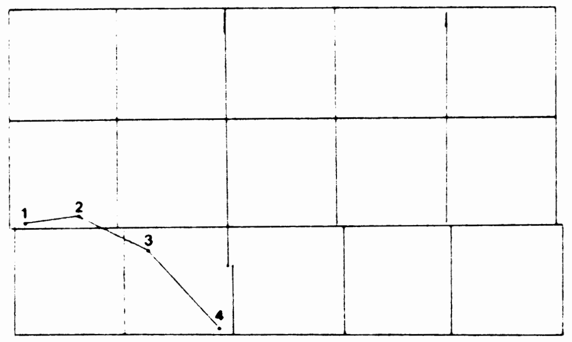
STRATIGRAPHIC CROSS-SECTION A-A'

PLATE I

STRATIGRAPHIC CROSS-SECTION B-B'

PLATE II





STRATIGRAPHIC CROSS-SECTION C-C′

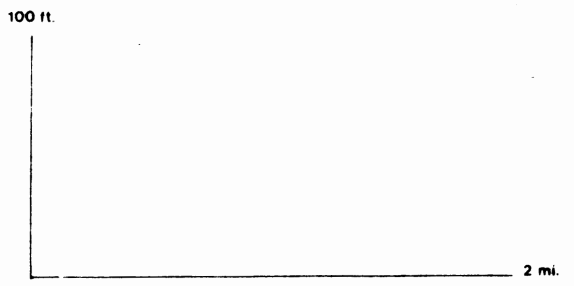


PLATE III

STRATIGRAPHIC CROSS-SECTION D-D'

PLATE IV

STRATIGRAPHIC CROSS-SECTION E-E'

PLATE V

STRATIGRAPHIC CROSS-SECTION F-F'

PLATE VI

M.S. THESIS
PHILIP PADGETT

PLATE VII

STRUCTURAL CONTOUR MAP

BASE OF HASKELL MARKER

C. I.=50 ft

M.S. THESIS
PHILIP PADGETT

PLATE IX

NET-SANDSTONE ISOPACH MAP

TONKAWA SANDSTONE

C. I.= 10ft